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RELEASES AND RECOVERIES OF DRIFT BOTTLES AND CARDS IN THE CENTRAL PACIFIC

By Richard A. Barkley, Bernard M. Ito,
and Robert P. Brown

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RELEASES AND RECOVERIES OF DRIFT BOTTLES AND CARDS IN THE CENTRAL PACIFIC

By

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ABSTRACT

Since January 1961, the Bureau of Commercial Fisheries Biological Laboratory in Honolulu has been releasing drift bottles and cards in the central Pacific Ocean. Data are presented on all releases and recoveries through June 1963, together with charts showing the release and recovery points. An analysis of the returns from the Hawaiian Islands shows that there is a seasonal change in the direction and speed of the current system near the Islands which coincides with changes in strength of the trade wind system. During the first half of the year the current moves at speeds of between 6 and 11 nautical miles per day and near Oahu and Kauai it moves toward the northwest, while in the latter half of the year the speed is 6 nautical miles per day or less, and the direction of flow is toward the west or somewhat south of west.

INTRODUCTION

In 1961 the Bureau of Commercial Fisheries Biological Laboratory in Honolulu began a series of drift bottle releases designed primarily to obtain more complete and detailed information on the currents near the Hawaiian Islands than was then available. It was clear that such information was required in order to interpret various kinds of oceanographic and biological information collected by the Laboratory near the Islands, and drift bottle techniques offered a means for obtaining considerable information in an economical way, preliminary to the use of more sophisticated and expensive procedures.

At that time, the information on surface and near-surface currents near the Hawaiian Islands consisted primarily of oceanographic station data taken by the Laboratory a decade earlier (McGary, 1955; Seckel, 1955), together with data on surface drift obtained from ship's log books (H. O. Publication nos. 570, 1947; and 569, 1950).

The dynamic topography of the sea surface near the Hawaiian Islands (McGary, 1955; Seckel, 1955) is characterized by an irregular series of eddies which vary considerably in size, number, and location. The eddies tend to obscure the patterns of mean flow, and because little is known about the growth and decay of such eddies, or of their movements, the information on mass transport which can be derived from the dynamic topography is valid for intervals of time of the order of a few days only.

Current charts based on ship's drift provide information on a monthly basis, and thus offer some continuity in time. However, the data are averaged over a number of years and over areas of 1 degree of latitude and longitude, so that the details of currents on a scale comparable to that of the individual islands are lost, since even Hawaii, the largest of the islands, is less than 60 nautical miles in mean diameter.

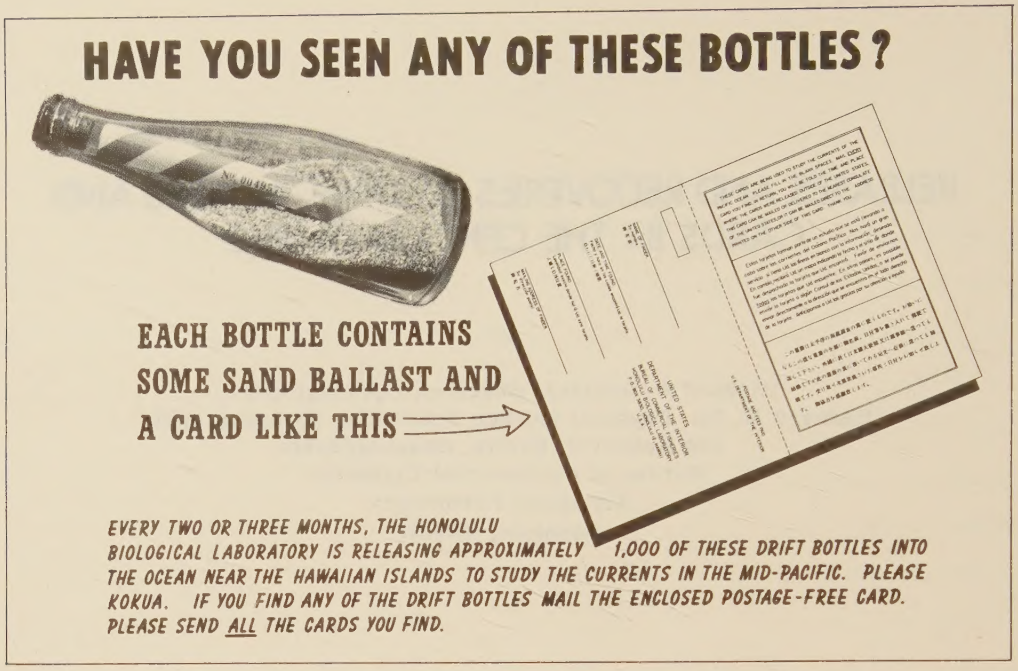
HAVE YOU SEEN ANY OF THESE BOTTLES?
EACH BOTTLE CONTAINS SOME SAND BALLAST AND A CARD LIKE THIS
EVERY TWO OR THREE MONTHS, THE HONOLULU BIOLOGICAL LABORATORY IS RELEASING APPROXIMATELY 1,000 OF THESE DRIFT BOTTLES INTO THE OCEAN NEAR THE HAWAIIAN ISLANDS TO STUDY THE CURRENTS IN THE MID-PACIFIC. PLEASE KOKUA. IF YOU FIND ANY OF THE DRIFT BOTTLES MAIL THE ENCLOSED POSTAGE-FREE CARD. PLEASE SEND ALL THE CARDS YOU FIND.

Figure 1.--Poster showing drift bottle and enclosed card. These posters were placed in schools and other public buildings to alert potential finders.

DESCRIPTION OF BOTTLES AND CARDS

Drift bottles were used initially, but were gradually replaced by drift cards during 1961. The drift bottle consisted of an 8-ounce clear glass bottle, ballasted with sand so that an inch of the neck protruded above the water (fig. 1). Cards were enclosed which contained instructions to the finder in English, Spanish, and Japanese, with a postcard attached which could be torn off for mailing (fig. 1). The postcards were numbered, postage paid, and self-addressed with blank spaces for the name and address of the finder and the time and place of recovery. The back of the card was printed with wide International Orange stripes to catch attention. These cards were folded up and wrapped once with pressure-sensitive tape to facilitate insertion in the bottle and to permit the finder to remove the card easily. The bottles were sealed with waxed corks.

In 1962 some experiments with drift cards sealed in plastic envelopes showed that the cards performed as well as the bottles and were much more convenient to store and use. The drift card consisted of a numbered, bright red postcard similar to that used in the bottles, but with the instructions to the finder printed on the back of the card (fig. 2). A weight was enclosed to make the card float vertically in the water so that its movements, like those of the bottles, would depend primarily on the currents in the uppermost 6 inches of the water column. The drift cards were sealed in polyethylene bags and then packaged in flimsy waxed-paper bags, in groups of 20, to ensure control of the serial number sequence and the number of cards per release; the waxed-paper bags were selected for their ability to come apart in the water in a minimum time, usually about 2 to 3 minutes.

The cost per bottle was estimated at 10 cents; the drift cards cost 11 cents each.

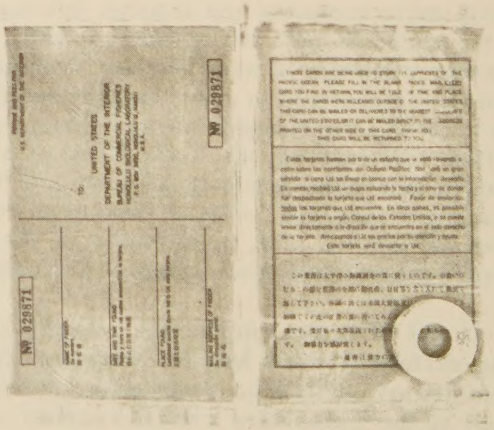

Figure 2.--Drift card used in this study.

NEW DRIFT CARD DESIGN

With experience in the manufacture and use of the drift cards described above, it became apparent that considerable improvement in the design was possible. Although none of the data presented herein were obtained with the new type of drift card, the new card will be illustrated and its manufacture briefly described because it represents a significant improvement in design which may be of value to others who are considering the use of drift cards.

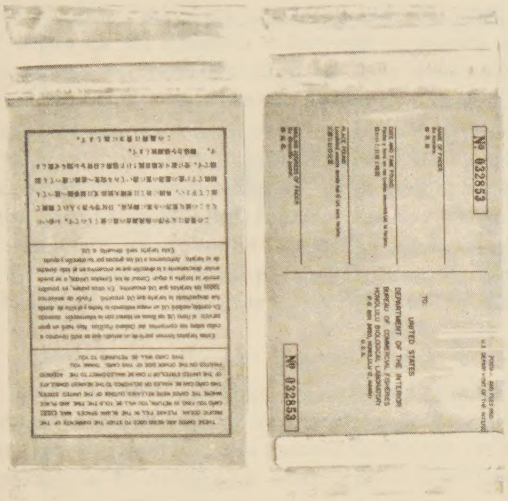

Figure 3.--New drift card design.

The important characteristics of the design (fig. 3) are:

1. A strip of metal ballast whose center of gravity is always near the long axis of the card, so that the card does not tend to float with one corner higher than the other, presenting an unbalanced area to the wind.

2. The absence of significant amounts of air in the card's compartment, so that the buoyancy can be concentrated at the end opposite the ballasted edge.

3. A controlled volume of air in a separate compartment of the plastic envelope, which virtually eliminates the possibility of sinking or of exposing too much area to the winds.

These cards are manufactured by placing the card and metal ballast strip in a polyethylene bag of 6-mil thickness, squeezing the card-filled portion between spring-loaded metal plates to remove the air, and sealing the upper edge of the card compartment. This leaves a 1-inch pocket at the upper end of the plastic bag, into which is inserted a length of soda straw cut to fit the width of the bag. When the upper compartment is sealed, the card is finished and ready to be placed in its waxed-paper bag with 19 other cards. All cards of this design floated upright without tilting, with a waterline at a level with the soda straw, exposing a uniform half-inch of the upper edge above water. The cost per card is 14 cents in quantity lots.

DRIFT BOTTLE AND CARD RELEASES AND RETURNS

Drift bottles, and later drift cards or cards and bottles together, were released whenever feasible by the Laboratory's research ship, the Charles H. Gilbert, beginning with cruise 51 in January 1961. In addition, the U. S. Coast and Geodetic Survey ship Surveyor released almost 3,000 cards during two cruises early in 1963, when that ship was working to the north of Midway Island, and a few bottles were released near Oahu in September 1961 by the M/V Broadbill, a fishing vessel then under charter to the Laboratory.

The releases are listed in the Appendix, which shows the cruise number (except in the cases of the Surveyor and Broadbill releases), the sequence number of the release, the number of bottles and/or cards in each release, and the date and location of the release. Initially there were 10 bottles in each release, but this number was later increased to 20 to improve the chances of multiple recoveries. On various occasions the number of bottles or cards per release were modified, and these exceptions are also noted in the tables.

The Appendix also shows the number of recoveries, if any, per release, as well as the date of each reported return, and the location where the bottle or card was found.

No reward was offered for reporting returns. The finder was sent a letter which thanked him for his assistance and outlined the project objectives, which told him when and where the bottle or card which he found had been released, and which also contained information on the minimum speed and the distance covered. Enclosed with each such letter was a chart showing the release point and the presumed path of the bottle or card, as well as the postcard mailed by the finder in reporting the recovery.

RESULTS

From January 1961 to June 1963, a total of 16,285 bottles and cards were released, and by January 1964 a total of 538 returns had been reported. This represents a recovery rate of 3.3 percent, which is remarkably high considering the ratio of the area covered by releases to the coastline available in the mid-Pacific. It can be compared, for example, with the return rate of 4.6 percent reported by Schwartzlose (1963) for releases off southern California.

On the island of Oahu, where some 80 percent of the population of the State of Hawaii lives, the timing of returns suggests that almost no bottles or cards remain undetected on land for more than about 1 day, which considerably enhances the reliability of the minimum velocities which can be computed from the time the drift bottle or cards spent in the water and the minimum distance covered. These minimum velocities range from less than 1 mile per day to about 15 miles per day, but within this range there are fairly distinct groups of speeds which appear to be characteristic of seasonal current patterns and of the distance traveled by the drift bottle or card. For returns to the islands of Oahu and Kauai, which represent the largest samples, the frequency distribution of computed minimum velocities shows modes at speeds of about 10 miles per day, 6 miles per day, 3 miles per day, and less than 1 mile per day. Table 1 shows the relationship between these characteristic modes in the velocity spectrum and the time of year and the distance traversed.

Table 1.--Most frequently occurring drift bottle and card speeds (miles per day) as a function of distance and time of year

Time of year	Distance (miles)		
	1 - 10	10 - 100	Over 100
Jan. to June	1/2, 3	1/2, 3, 6	)
			) 6, 9
July to Dec.	3, 9	6, 11	)

Note: The underlined values represent the dominant modal speeds in each case.

The sample sizes on which table 1 is based are about 50 returns in each case, except for the two sets of values for distances of 100 miles or less from July to December, each of which has more than 100 returns represented in it. The 49 returns from distances greater than 100 miles were not enough to permit breakdown by time of year.

The choice of time periods in table 1 is based on a distinct seasonal pattern in the direction of travel of the drift bottles and cards. Figures 4 through 9 show the locations of releases and recoveries, together with the inferred trajectories. The data are grouped by season, except for the period from April to June, where it was possible to chart returns by month. Figure 10 shows the returns from releases outside of the immediate vicinity of the Hawaiian Islands. All releases are shown in figures 4 through 10 as dots; releases with returns have trajectories associated with them. In cases where more than one return resulted from a release, only one trajectory is shown, unless the recovery points were relatively widely separated. Trajectories were drawn using the convention that trajectories from near-simultaneous releases cannot cross; in figure 10, the trajectories were drawn with the aid of the Atlas of Surface Currents (H. O. Publication no. 570, 1947).

During Charles H. Gilbert cruises 58 and 63, in July 1962 and January to March 1963, respectively, both drift bottles and cards were released simultaneously. This was part of a series of tests to determine the relative effectiveness of the two packages. Essentially the same proportions of both bottles and cards were reported found, and there was no significant difference in the directions of movement, so that the two packages were considered equivalent in performance.

DISCUSSION

The velocity figures shown in table 1 suggest a seasonal change in the velocity of the North Pacific Equatorial Current in the latitude of the Hawaiian Islands. In the early part of the year there was little evidence of speeds of drift of more than 6 nautical miles per day; later in the year, and particularly in returns from more than 10 nautical miles away, there was a considerable proportion of returns with minimum velocities of from 9 to 11 nautical miles per day.

This change in speed coincides with a change in the direction of drift. Figures 4 through 6 show that most recoveries during the first half of the year came from releases made to the south of the recovery points, so that the bottles and cards must have been carried north through the inter-island channels before coming ashore on the windward (northeast) coasts of the Islands. Figures 7 and 8, on the other hand, show a much

greater proportion of returns from releases to the east. Thus, a change in the angle of incidence of the current relatively near shore must take place about June; before then, the drift is roughly parallel to the Islands, with a considerable northward component, while later in the year the flow is primarily from the east or northeast. The evidence for this change is particularly clear when figure 4 is compared with figures 7 and 8, because the periods represented on these charts all contain releases made northeast of the Islands.

As might be expected, the change in the speed and direction of drift with time of year coincides in a general way with the changes in the North Pacific trade wind system. In October through April the windspeeds are lower and light, variable winds are more frequent than in May through September, when the winds exceed 14 miles per hour 50 percent of the time, and 80 to 95 percent of the time are from the northeast quadrant (Blumenstock, 1961).

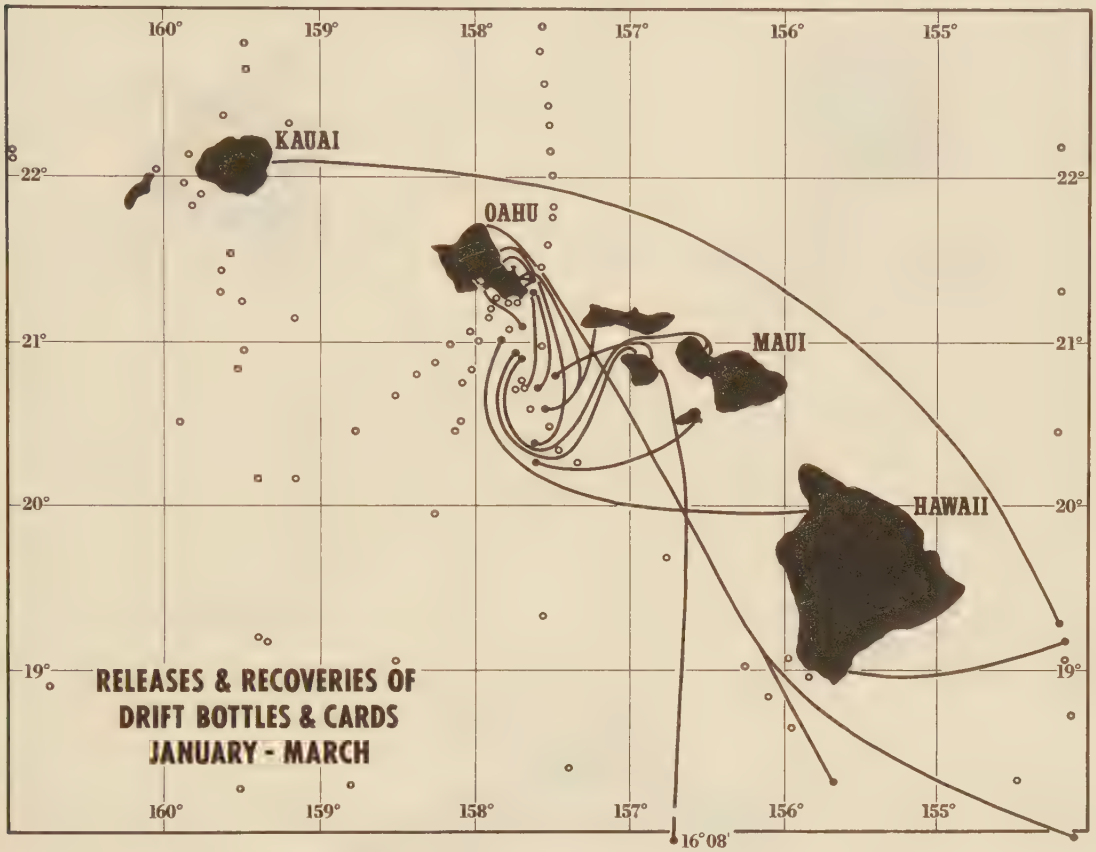

Figure 4.--Reported returns of drift bottles and cards, January - March.

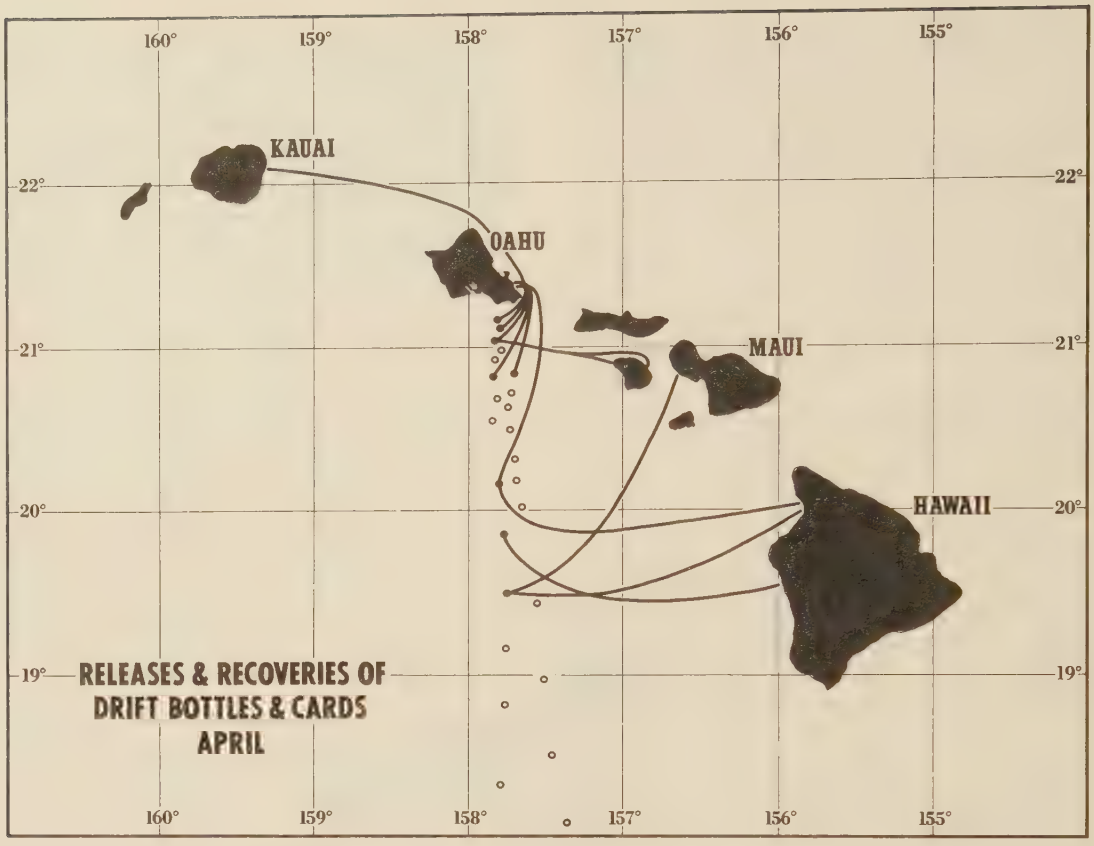

Figure 5.--Reported returns of drift bottles and cards, April.

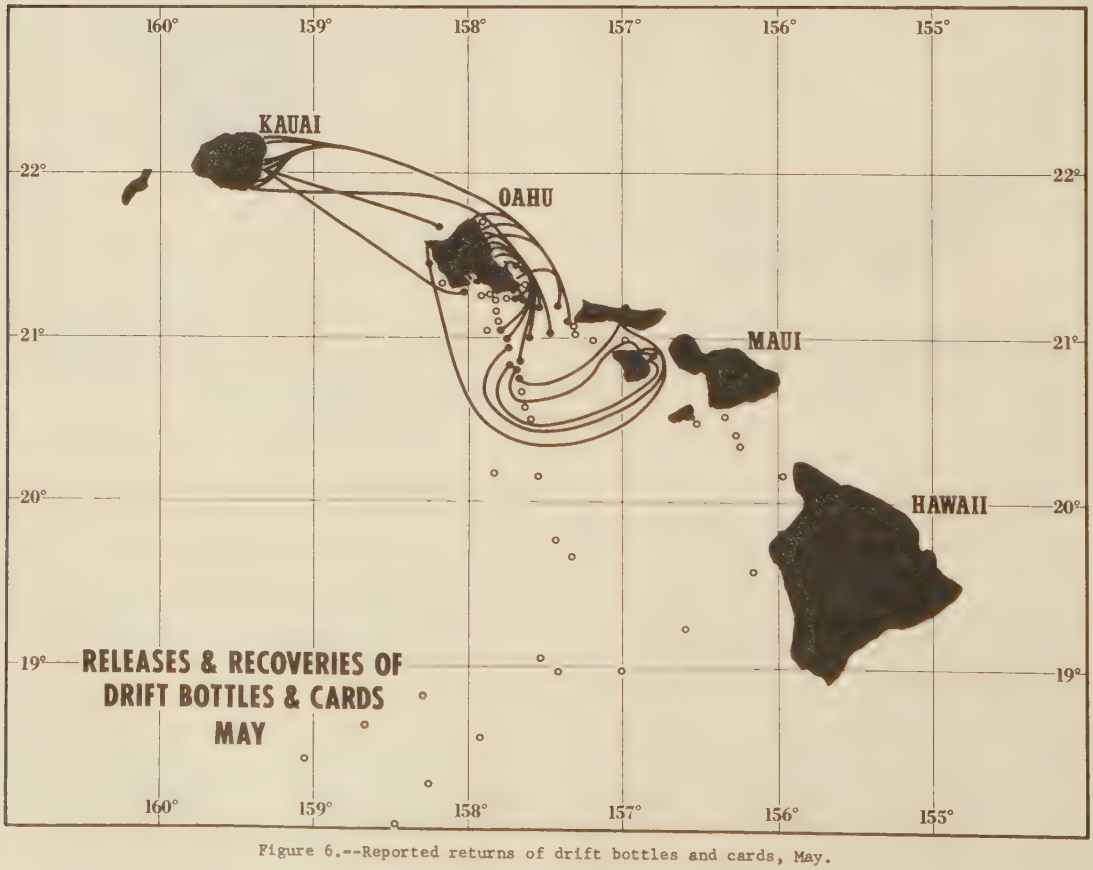

Figure 6.--Reported returns of drift bottles and cards, May.

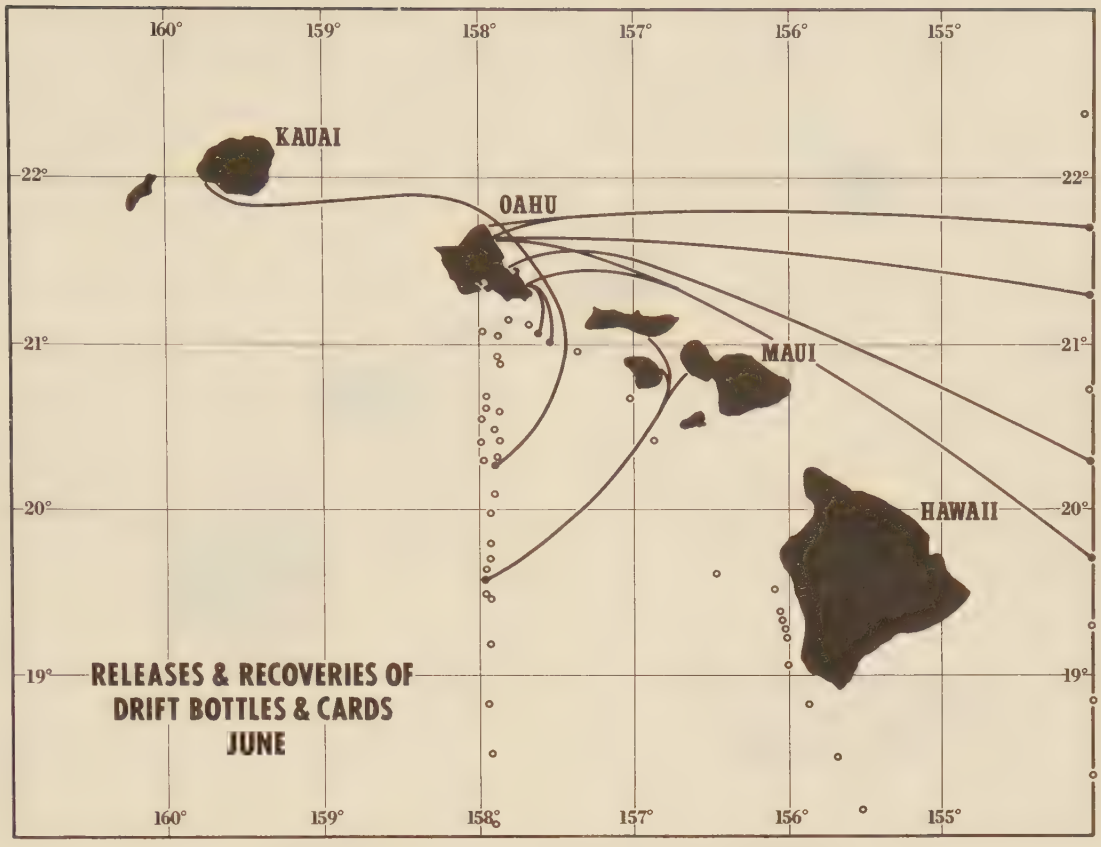

Figure 7.--Reported returns of drift bottles and cards, June.

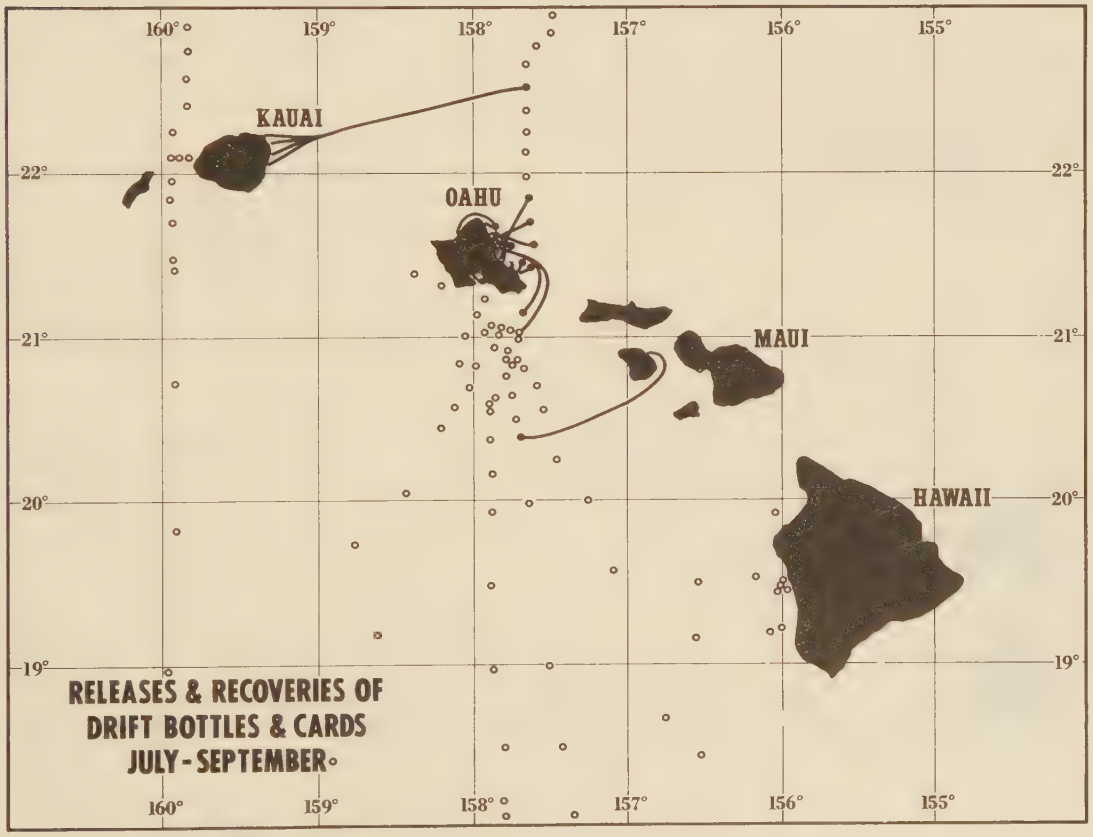

Figure 8.--Reported returns of drift bottles and cards, July - September.

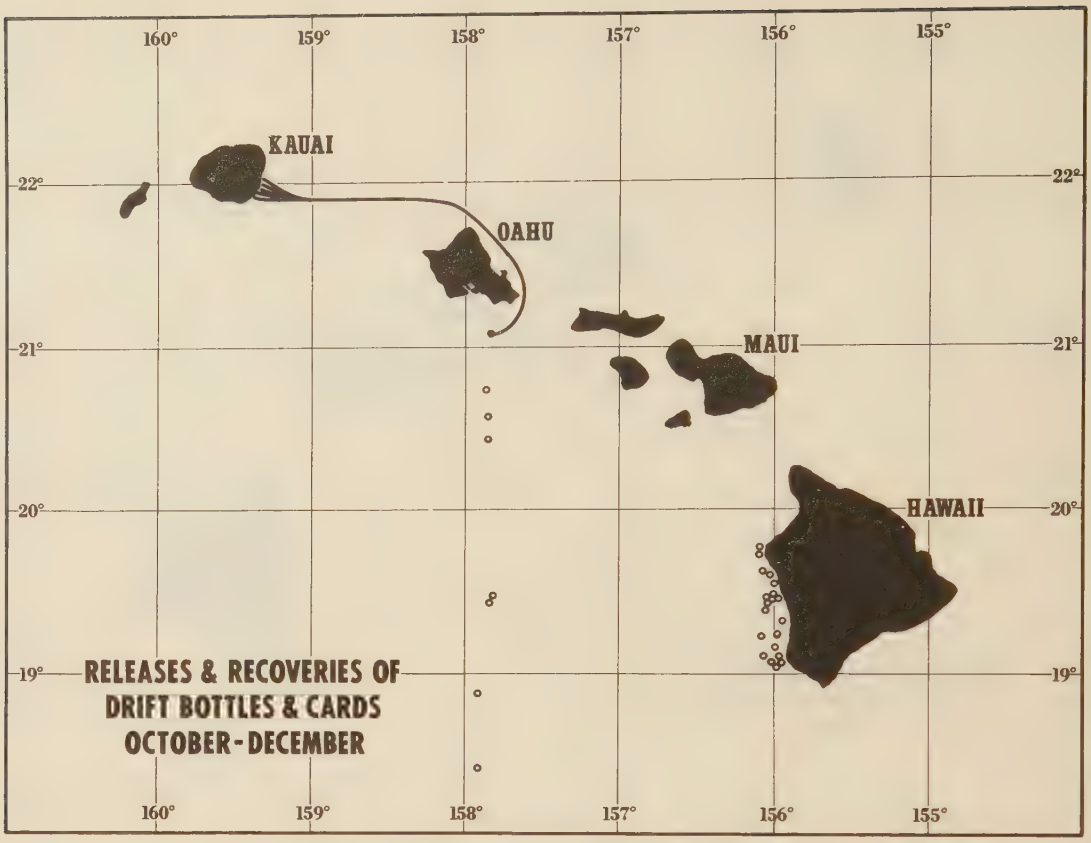

Figure 9.--Reported returns of drift bottles and cards, October - December.

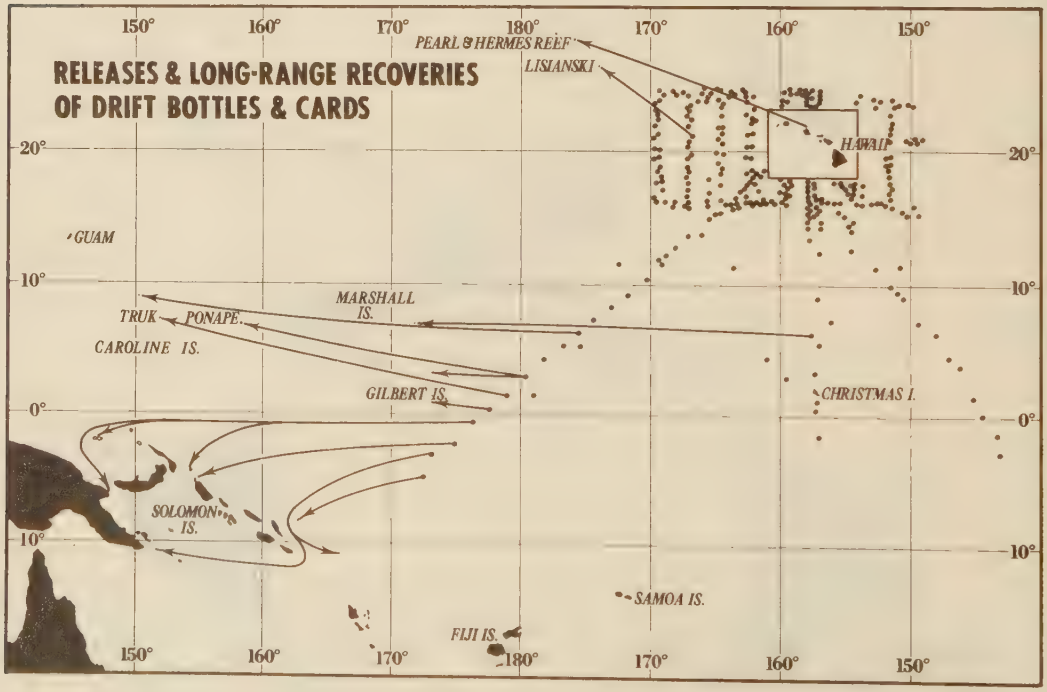

Figure 10.--Returns of drift bottles and cards reported from outside the Hawaiian Islands.

SUMMARY

1. From January 1961 through June 1963, a total of 16,285 drift bottles and cards were released in the central and western Pacific Ocean, the majority in the vicinity of the Hawaiian Islands.

2. By January 1964 there had been 538 returns.

3. The pattern of recoveries from the Hawaiian Islands suggests that the current system near the Islands varies seasonally in strength, with velocities during May to September of about 6 to 11 nautical miles per day, and 6 nautical miles per day or less during October to April, as computed from minimum speeds of drift of both bottles and cards.

4. The pattern of recoveries also suggests a seasonal change in the direction of drift in the immediate vicinity of Oahu; from January to May the drift was predominantly to the northwest, roughly parallel to the Island chain, while during June to December the drift was primarily to the west or somewhat south of west.

5. In general, the pattern of surface drift, and its speed, coincide with the seasonal changes in strength of the trade wind system.

ACKNOWLEDGMENTS

The captain and the crew of the U. S. Coast and Geodetic Survey ship Surveyor assisted in releasing drift cards. Many others cooperated in reporting recovered bottles and cards.

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APPENDIX

The following table contains data on drift card and bottle releases and recoveries from January 1961 to June 1963. The data are grouped by the cruise on which the releases were made and are presented in the chronological order of the cruises.

CHARLES H. GILBERT CRUISE 51 - Jan. 12 - Feb. 28, 1961

Bottles (10 per batch) release batch no.	Release data			Recovery data				
	Date	Lat. (N.)	Long. (W.)	Number returns	Date	Lat. (N.)	Long. (W.)	Locality
51-1	1/18/61	21°03'	157°45'					
51-2	1/18/61	20°55'	157°42'	4	1/24/61	20°55'	156°29'	Maui
				1	2/25/61	21°43'	157°59'	Oahu
51-3	1/18/61	20°43'	157°37'	1	4/16/61	21°34'	157°53'	Oahu
51-4	1/18/61	20°36'	157°34'	1	2/ 5/61	21°06'	157°14'	Molokai
				1	2/22/61	21°24'	157°45'	Oahu
51-5	1/18/61	20°29'	157°32'					
51-6	1/18/61	20°21'	157°28'					
51-7	1/18/61	20°15'	157°21'					
51-8	1/18/61	19°42'	156°47'					
51-9	1/19/61	19°02'	156°17'					
51-10	1/19/61	18°51'	156°07'					
51-11	1/19/61	18°40'	155°58'					
51-12	1/19/61	18°19'	155°40'	1	2/19/61	21°34'	157°53'	Oahu
				1	2/25/61	21°43'	157°59'	Oahu
51-13	1/19/61	17°39'	155°05'					
51-14	1/19/61	16°56'	154°31'					
51-15	1/20/61	16°17'	154°01'					
51-16	1/20/61	15°56'	153°14'					
51-17	1/20/61	16°03'	152°25'					
51-18	1/20/61	16°09'	151°53'					
51-19	1/21/61	16°40'	151°35'					
51-20	1/21/61	17°37'	151°40'					
51-21	1/21/61	18°26'	151°43'					
51-22	1/21/61	18°58'	151°43'					
51-23	1/22/61	19°53'	151°46'					
51-24	1/22/61	20°51'	151°36'					
51-25	1/22/61	21°39'	151°28'					
51-26	1/22/61	22°10'	151°21'					
51-27	1/23/61	23°04'	151°10'					
51-28	1/23/61	23°47'	151°19'					
51-29	1/23/61	23°47'	152°03'					
51-30	1/23/61	23°52'	152°49'					
51-31	1/24/61	23°58'	153°36'					
51-32	1/24/61	23°02'	154°11'					
51-33	1/24/61	22°10'	154°12'					
51-34	1/25/61	21°18'	154°12'					
51-35	1/25/61	20°26'	154°12'					
51-36	1/25/61	19°18'	154°10'	1	8/13/61	22°04'	159°19'	Kauai
51-37*	1/25/61	19°24'	154°10'					
51-38	1/25/61	19°11'	154°09'	1	2/25/61	18°58'	155°36'	Hawaii
51-39	1/25/61	18°44'	154°08'					
51-40	1/26/61	17°58'	154°06'	1	6/ 6/61	21°20'	157°42'	Oahu
51-41	1/26/61	17°33'	154°06'					
51-42	1/26/61	17°09'	154°08'					
51-43	1/26/61	16°15'	154°11'					
51-44	1/26/61	16°05'	154°58'					
51-45	1/27/61	16°06'	155°50'					
51-46	1/27/61	16°08'	156°44'					
51-47	1/27/61	16°49'	157°07'					

*20 bottles released

CHARLES H. GILBERT CRUISE 51 - Jan. 12 - Feb. 28, 1961--Con.

Bottles (10 per batch) release batch no.	Release data			Recovery data				
	Date	Lat. (N.)	Long. (W.)	Number returns	Date	Lat. (N.)	Long. (W.)	Locality
51-48	1/27/61	17°30'	157°13'					
51-49	1/27/61	17°39'	157°16'					
51-50	1/28/61	18°25'	157°24'					
51-51	1/28/61	19°21'	157°34'					
51-52	1/28/61	20°14'	157°37'	1	3/26/61	21°22'	157°42'	Oahu
				1	2/10/62	20°31'	156°34'	Kahoolawe
51-53	1/28/61	20°24'	157°36'	1	2/18/61	21°22'	157°42'	Oahu
				1	2/22/61	21°24'	157°45'	Oahu
				1	2/22/61	21°28'	157°48'	Oahu
				1	2/22/61	21°22'	157°42'	Oahu
51-54	1/28/61	20°36'	157°39'					
51-55	1/28/61	20°44'	157°42'	1	3/ 7/61	21°17'	157°42'	Oahu
				1	3/21/61	20°49'	156°49'	Lanai
51-56	1/28/61	20°54'	157°46'	1	4/ 8/61	20°54'	156°54'	Lanai
51-57	1/28/61	21°04'	157°48'	1	3/ 8/61	20°00'	155°50'	Hawaii
51-58	2/ 1/61	21°09'	157°56'					
51-59	2/ 1/61	21°01'	157°59'					
51-60	2/ 1/61	20°51'	158°02'					
51-61	2/ 1/61	20°45'	158°04'					
51-62	2/ 1/61	20°31'	158°07'					
51-63	2/ 1/61	20°27'	158°09'					
51-64	2/ 1/61	19°59'	158°17'					
51-65	2/ 1/61	19°04'	158°32'					
51-66	2/ 2/61	18°19'	158°49'					
51-67	2/ 2/61	17°30'	159°08'					
51-68	2/ 2/61	16°45'	159°20'					
51-69	2/ 2/61	15°58'	159°32'					
51-70	2/ 3/61	16°05'	160°22'					
51-71	2/ 3/61	16°07'	161°25'					
51-72	2/ 3/61	16°04'	162°18'					
51-73	2/ 3/61	16°51'	162°29'					
51-74	2/ 4/61	17°37'	162°32'					
51-75	2/ 4/61	18°28'	162°32'					
51-76	2/ 4/61	19°48'	162°29'					
51-77	2/ 4/61	20°17'	162°27'					
51-78	2/ 5/61	21°06'	162°27'					
51-79	2/ 5/61	22°02'	162°26'					
51-80	2/ 5/61	22°04'	160°08'					
51-81	2/ 6/61	22°02'	160°02'					
51-82	2/ 7/61	22°06'	160°58'					
51-83	2/ 7/61	22°10'	161°58'					
51-84	2/ 7/61	22°40'	162°30'					
51-85	2/ 7/61	23°34'	162°28'					
51-86	2/ 8/61	23°58'	162°48'					
51-87	2/ 8/61	23°56'	163°47'					
51-88	2/ 8/61	23°56'	164°42'					
51-89	2/ 8/61	23°57'	165°22'					
51-90	2/ 9/61	23°57'	166°05'					
51-91	2/ 9/61	23°45'	167°00'					
51-92	2/10/61	23°00'	167°04'					
51-93	2/10/61	22°32'	167°11'					
51-94	2/10/61	21°45'	167°06'					
51-95	2/10/61	20°57'	167°00'					
51-96	2/11/61	20°06'	166°59'					
51-97	2/11/61	19°40'	166°57'					
51-98	2/11/61	18°25'	167°02'					
51-99	2/11/61	17°36'	167°06'					
51-100	2/12/61	16°46'	167°11'					
51-101	2/12/61	15°58'	167°15'					
51-102	2/12/61	15°58'	168°13'					
51-103	2/13/61	16°30'	169°38'					
51-104	2/15/61	17°01'	169°06'					

CHARLES H. GILBERT CRUISE 51 - Jan. 12 - Feb. 28, 1961--Con.

Bottles (10 per batch) release batch no.	Release data			Recovery data				
	Date	Lat. (N.)	Long. (W.)	Number returns	Date	Lat. (N.)	Long. (W.)	Locality
51-105*	2/15/61	17°55'	169°14'					
51-106	2/15/61	18°46'	169°18'					
51-107	2/15/61	19°27'	169°20'					
51-108	2/16/61	20°08'	169°21'					
51-109	2/16/61	21°08'	169°22'					
51-110	2/16/61	22°01'	169°26'					
51-111	2/16/61	22°49'	169°32'					
51-112	2/17/61	23°28'	169°36'					
51-113	2/17/61	24°01'	169°10'					
51-114	2/17/61	24°02'	168°11'					
51-115	2/17/61	24°02'	167°20'					
51-116	2/18/61	23°58'	166°44'					
51-117	2/19/61	23°56'	166°02'					
51-118	2/19/61	24°02'	165°16'					
51-119	2/20/61	24°02'	164°34'					
51-120	2/20/61	23°08'	164°34'					
51-121	2/20/61	21°42'	164°33'					
51-122	2/20/61	21°15'	164°32'					
51-123	2/21/61	20°21'	164°30'					
51-124	2/21/61	19°57'	164°30'					
51-125	2/21/61	18°38'	164°30'					
51-126	2/21/61	17°44'	164°32'					
51-127	2/22/61	16°46'	164°32'					
51-128	2/22/61	15°58'	164°27'					
51-129	2/22/61	15°58'	163°50'					
51-130	2/22/61	16°00'	163°10'					
51-131	2/23/61	16°06'	162°30'					
51-132	2/23/61	16°12'	161°56'					
51-133	2/23/61	16°12'	161°18'					
51-134	2/23/61	16°10'	160°38'					
51-135	2/24/61	16°07'	159°48'					
51-136	2/24/61	16°19'	159°30'					
51-137	2/24/61	17°19'	159°34'					
51-138	2/24/61	18°17'	159°32'					
51-139	2/25/61	19°13'	159°24'					
51-140	2/25/61	20°11'	159°23'					
51-141	2/25/61	20°59'	159°28'					
51-142	2/25/61	21°10'	159°29'					
51-143	2/25/61	21°17'	159°29'					
51-144	2/25/61	21°27'	159°39'					
51-145	2/25/61	21°34'	159°34'					
51-146	2/25/61	21°39'	159°39'					
51-147	2/25/61	21°50'	159°48'	1	4/ 1/61	21°50'	160°08'	Niihau
51-148	2/26/61	21°58'	159°51'	1	3/ 3/61	22°03'	160°06'	Niihau
51-149	2/26/61	22°06'	159°50'					
51-150	2/26/61	22°14'	159°44'					
51-151	2/26/61	22°21'	159°37'					
51-152	2/26/61	22°29'	159°31'					
51-153	2/26/61	22°38'	159°28'					
51-154	2/26/61	22°46'	159°28'					
51-155	2/26/61	23°28'	159°25'					
51-156	2/26/61	24°01'	159°06'					
51-157	2/26/61	24°05'	158°39'					
51-158	2/27/61	24°11'	158°06'					
51-159	2/27/61	24°04'	157°39'					
51-160	2/27/61	23°53'	157°37'					
51-161	2/27/61	23°44'	157°37'					
51-162	2/27/61	23°29'	157°37'					

*5 bottles released

CHARLES H. GILBERT CRUISE 51 - Jan. 12 - Feb. 28, 1961--Con.

Bottles (10 per batch) release batch no.	Release data			Recovery data				
	Date	Lat. (N.)	Long. (W.)	Number returns	Date	Lat. (N.)	Long. (W.)	Locality
51-163	2/27/61	23°20'	157°36'					
51-164	2/27/61	23°09'	157°35'					
51-165	2/27/61	23°02'	157°34'					
51-166	2/27/61	22°53'	157°34'					
51-167	2/27/61	22°44'	157°34'					
51-168	2/27/61	22°34'	157°33'					
51-169	2/27/61	22°26'	157°32'					
51-170	2/27/61	22°18'	157°32'					
51-171	2/28/61	22°08'	157°31'					
51-172	2/28/61	22°00'	157°31'					
51-173	2/28/61	21°50'	157°30'					
51-174	2/28/61	21°44'	157°30'					
51-175	2/28/61	21°35'	157°32'					
51-176	2/28/61	21°27'	157°35'					
51-177	2/28/61	21°18'	157°38'	1	3/ 4/61	21°17'	157°42'	Oahu
				1	3/ 5/61	21°17'	157°42'	Oahu
51-178	2/28/61	21°15'	157°44'					
51-179	2/28/61	21°15'	157°48'					
51-180	2/28/61	21°17'	157°51'					

CHARLES H. GILBERT CRUISE 52 - March 27 - May 17, 1961

Bottles (10 per batch) release batch no.	Release data			Recovery data				
	Date	Lat. (N.)	Long. (W.)	Number returns	Date	Lat. (N.)	Long. (W.)	Locality
52-1	5/ 4/61	21°11'	157°49'					
52-2	5/ 4/61	21°06'	157°48'					
52-3	5/ 4/61	21°03'	157°47'	1	5/11/61	21°22'	157°42'	Oahu
				2	5/12/61	21°24'	157°45'	Oahu
				1	5/13/61	21°39'	157°56'	Oahu
				1	5/14/61	21°37'	157°55'	Oahu
				1	5/22/61	21°37'	157°55'	Oahu
52-4	5/ 4/61	20°59'	157°45'	1	5/13/61	21°28'	157°48'	Oahu
				1	5/28/61	21°53'	159°28'	Kauai
52-5	5/ 4/61	20°55'	157°45'	1	5/10/61	20°49'	156°49'	Lanai
				1	5/ 7/61	20°48'	157°00'	Lanai
				1	5/10/61	20°52'	156°51'	Lanai
52-6	5/ 4/61	20°51'	157°43'	1	5/10/61	20°52'	156°51'	Lanai
				1	5/29/61	20°58'	156°51'	Lanai
				1	5/14/61	20°51'	157°01'	Lanai
52-7	5/ 4/61	20°49'	157°42'	1	5/22/61	21°35'	157°54'	Oahu
52-8	5/ 4/61	20°45'	157°41'	1	5/17/61	21°06'	156°46'	Molokai
52-9	5/ 4/61	20°40'	157°39'					
52-10	5/ 4/61	20°35'	157°38'					
52-11	5/ 4/61	20°31'	157°36'	1	5/27/61	21°50'	160°03'	Niihau
52-12	5/ 4/61	20°09'	157°34'					
52-13	5/ 5/61	19°45'	157°27'					
52-14	5/ 5/61	19°21'	157°20'					
52-15	5/ 5/61	19°04'	157°33'					
52-16	5/ 5/61	18°38'	157°26'					
52-17	5/ 5/61	18°49'	158°18'					
52-18	5/ 5/61	18°38'	158°41'					
52-19	5/ 5/61	18°26'	159°04'					
52-20	5/ 6/61	18°03'	158°29'					
52-21	5/ 6/61	18°17'	158°14'					
52-22	5/ 6/61	18°34'	157°56'					
52-23	5/ 6/61	18°46'	157°33'					
52-24	5/ 7/61	18°59'	157°01'					
52-25	5/ 7/61	19°15'	156°36'					
52-26	5/ 7/61	19°35'	156°10'					
52-27	5/ 8/61	20°09'	155°57'					

CHARLES H. GILBERT CRUISE 52 - March 27 - May 17, 1961--Con.

Bottles (10 per batch) release batch no.	Release data			Recovery data				
	Date	Lat. (N.)	Long. (W.)	Number returns	Date	Lat. (N.)	Long. (W.)	Locality
52-28	5/ 8/61	20°25'	156°15'	1	5/18/61	21°28'	157°45'	Oahu
52-29	5/ 8/61	20°30'	156°21'	1	5/20/61	21°37'	157°55'	Oahu
52-30	5/ 8/61	20°54'	156°48'	1	5/15/61	20°49'	156°59'	Lanai
				1	5/21/61	20°49'	156°59'	Lanai
				1	9/23/61	20°49'	156°59'	Lanai
				1	11/4/61	20°49'	156°49'	Lanai
				1	5/10/61	20°54'	156°53'	Lanai
				1	5/10/61	20°52'	156°52'	Lanai
52-31	5/ 8/61	20°58'	156°58'					
52-32	5/ 8/61	21°05'	157°18'	1	5/ 9/61	21°24'	157°45'	Oahu
				1	5/13/61	21°39'	157°56'	Oahu
				1	5/14/61	21°35'	157°54'	Oahu
				1	5/30/61	22°09'	159°19'	Kauai
52-33	5/ 8/61	21°00'	157°36'	2	5/10/61	21°22'	157°42'	Oahu
				1	5/13/61	21°17'	157°42'	Oahu
52-34	5/ 8/61	21°14'	157°44'	1	6/18/61	21°53'	159°28'	Kauai
52-35	5/12/61	21°17'	157°51'					
52-36*	5/12/61	21°15'	158°48'					
52-37*	5/12/61	21°14'	157°43'	1	7/ 4/61	21°17'	157°42'	Oahu
				1	5/14/61	21°15'	157°49'	Oahu
52-38*	5/12/61	21°13'	157°38'	1	5/17/61	21°28'	157°50'	Oahu
				1	5/13/61	21°16'	157°43'	Oahu
				1	5/15/61	21°25'	157°48'	Oahu
				1	5/15/61	21°19'	157°39'	Oahu
52-39*	5/12/61	21°12'	157°34'	2	5/15/61	21°24'	157°45'	Oahu
				5	5/14/61	21°24'	157°45'	Oahu
				1	5/13/61	21°24'	157°45'	Oahu
				1	6/ 5/61	21°24'	157°45'	Oahu
				1	5/13/61	21°24'	157°43'	Oahu
				1	5/17/61	21°30'	157°51'	Oahu
52-40*	5/12/61	21°12'	157°26'	1	5/23/61	22°10'	159°19'	Kauai
				1	6/ 3/61	22°03'	159°20'	Kauai
				2	5/17/61	21°34'	157°53'	Oahu
				1	8/13/61	21°55'	159°25'	Kauai
52-41*	5/12/61	21°10'	157°23'					
52-42*	5/12/61	21°07'	157°20'	1	5/21/61	22°04'	159°20'	Kauai
				2	5/27/61	22°03'	159°20'	Kauai
				1	5/26/61	21°55'	159°25'	Kauai
52-43*	5/12/61	21°04'	157°18'	1	5/26/61	21°58'	159°21'	Kauai
				1	5/28/61	22°03'	159°20'	Kauai
				1	6/ 2/61	22°13'	159°23'	Kauai
				1	6/ 1/61	21°59'	159°20'	Kauai
52-44*	5/12/61	21°00'	157°15'	1	5/30/61	21°43'	157°59'	Oahu
52-45*	5/12/61	20°58'	157°12'	1	5/27/61	22°09'	159°19'	Kauai
				1	5/15/61	21°43'	157°59'	Oahu
				1	6/ 2/61	21°43'	157°59'	Oahu
52-46*	5/17/61	21°16'	157°50'	1	6/21/61	21°43'	157°59'	Oahu
				1	6/30/61	21°24'	157°45'	Oahu
52-47*	5/17/61	21°14'	157°42'	1	6/ 3/61	21°22'	157°42'	Oahu
52-48*	5/17/61	21°19'	157°38'	1	5/18/61	21°19'	157°39'	Oahu
				1	5/19/61	21°24'	157°43'	Oahu
				1	6/29/61	21°19'	157°39'	Oahu
				2	5/18/61	21°20'	157°42'	Oahu
				1	5/17/61	21°20'	157°42'	Oahu
52-49*	5/17/61	21°24'	157°40'	1	5/18/61	21°24'	157°45'	Oahu
				14	5/18/61	21°24'	157°43'	Oahu
				1	5/20/61	21°24'	157°43'	Oahu
52-50*	5/17/61	21°28'	157°42'	1	5/19/61	21°28'	157°50'	Oahu
				1	5/21/61	21°28'	157°50'	Oahu
				2	5/19/61	21°28'	157°50'	Oahu
				2	5/20/61	21°28'	157°50'	Oahu

* 20 bottles per batch.

CHARLES H. GILBERT CRUISE 52 - March 27 - May 17, 1961--Con.

Bottles (10 per batch) release batch no.	Release data			Recovery data				
	Date	Lat. (N.)	Long. (W.)	Number returns	Date	Lat. (N.)	Long. (W.)	Locality
				1	5/24/61	21°25'	157°48'	Oahu
				1	7/19/61	21°28'	157°51'	Oahu
52-51*	5/17/61	21°34'	157°48'	1	5/25/61	21°24'	157°45'	Oahu
				1	5/19/61	21°37'	157°55'	Oahu
				1	5/20/61	21°43'	157°59'	Oahu
52-52*	5/17/61	21°42'	157°55'	3	5/25/61	21°43'	157°49'	Oahu
				2	5/27/61	21°24'	157°45'	Oahu
				2	5/28/61	21°24'	157°45'	Oahu
52-53*	5/17/61	21°43'	158°02'					
52-54**	5/17/61	21°39'	158°12'	1	6/13/61	22°05'	159°19'	Kauai
				1	7/ 3/61	22°03'	159°20'	Kauai
52-55*	5/17/61	21°35'	159°19'					
52-56***	5/17/61	21°27'	158°15'	1	6/ 9/61	21°35'	158°17'	Oahu
				1	8/ 1/62	21°05'	157°02'	Molokai
52-57***	5/17/61	21°20'	158°10'					
52-58***	5/17/61	21°17'	158°02'	1	5/18/61	21°18'	158°07'	Oahu
				1	7/15/61	22°03'	159°20'	Kauai
52-59***	5/17/61	21°17'	157°53'					

*20 bottles per batch.
**17 bottles per batch.
***40 bottles per batch.

CHARLES H. GILBERT CRUISE 53 - June 20 to July 30, 1961

Bottles (10 per batch) release batch no.	Release data			Recovery data				
	Date	Lat. (N.)	Long. (W.)	Number returns	Date	Lat. (N.)	Long. (W.)	Locality
53-1	6/23/61	21°20'	157°53'					
53-2	6/23/61	21°13'	157°47'					
53-3	6/23/61	21°08'	157°41'					
53-4	6/23/61	21°04'	157°35'	4	6/27/61	21°17'	157°42'	Oahu
				1	6/28/61	21°17'	157°42'	Oahu
				1	6/27/61	21°19'	157°39'	Oahu
				1	6/27/61	21°24'	157°43'	Oahu
				1	6/29/61	21°19'	157°39'	Oahu
53-5	6/23/61	21°01'	157°29'	1	6/26/61	21°22'	157°42'	Oahu
				2	6/27/61	21°17'	157°42'	Oahu
				1	6/28/61	21°17'	157°42'	Oahu
				1	6/29/61	21°19'	157°39'	Oahu
53-6	6/23/61	20°57'	157°23'					
53-7	6/23/61	20°40'	157°02'					
53-8	6/23/61	20°26'	156°21'					
53-9	6/24/61	19°56'	156°27'					
53-10	6/24/61	19°32'	156°06'					
53-11	6/24/61	19°24'	156°04'					
53-12	6/24/61	19°21'	156°03'					
53-13	6/24/61	19°17'	156°02'					
53-14	6/24/61	19°13'	156°02'					
53-15	6/24/61	19°05'	156°00'					
53-16	6/24/61	18°49'	155°51'					
53-17	6/24/61	18°30'	155°41'					
53-18	6/24/61	18°11'	155°32'					
53-19	6/24/61	17°52'	155°20'					
53-20	6/25/61	17°35'	155°07'					
53-21	6/25/61	17°17'	154°54'					
53-22	6/25/61	16°59'	154°42'					
53-23	6/25/61	16°39'	154°27'					
53-24	6/25/61	16°04'	153°59'					
53-25	6/25/61	16°02'	153°38'					

CHARLES H. GILBERT CRUISE 53 - June 20 to July 30, 1961--Con.

Bottles (10 per batch) release batch no.	Release data			Recovery data				
	Date	Lat. (N.)	Long. (W.)	Number returns	Date	Lat. (N.)	Long. (W.)	Locality
53-26	6/26/61	16°06'	152°56'					
53-27	6/26/61	16°11'	152°10'					
53-28	6/26/61	16°30'	151°38'					
53-29	6/26/61	17°16'	151°38'					
53-30	6/27/61	18°07'	151°37'					
53-31	6/27/61	18°58'	151°36'					
53-32	6/27/61	19°46'	151°35'					
53-33	6/28/61	21°22'	151°33'					
53-34	6/28/61	22°12'	151°32'					
53-35	6/28/61	23°00'	152°32'					
53-36	6/29/61	23°50'	153°51'					
53-37	6/29/61	23°21'	154°05'					
53-38	6/29/61	22°23'	154°05'					
53-39	6/30/61	21°43'	154°02'	1	8/ 9/61	21°43'	157°59'	Oahu
				1	8/ 8/61	21°39'	157°56'	Oahu
53-40	6/30/61	21°17'	154°02'	1	8/ 4/61	21°39'	157°56'	Oahu
53-41	6/30/61	20°46'	154°01'					
53-42	6/30/61	20°15'	154°01'	1	8/10/61	21°35'	157°54'	Oahu
53-43	6/30/61	19°43'	154°00'	1	7/29/61	21°24'	157°45'	Oahu
				1	7/27/61	21°39'	157°56'	Oahu
53-44	6/30/61	19°16'	154°00'					
53-45	6/30/61	18°50'	154°00'					
53-46	6/30/61	18°25'	154°00'					
53-47	7/ 1/61	18°00'	154°00'					
53-48	7/ 1/61	17°33'	154°16'					
53-49	7/ 1/61	17°07'	154°32'					
53-50	7/ 1/61	16°40'	154°48'					
53-51	7/ 1/61	16°21'	155°00'					
53-52	7/ 1/61	16°12'	155°25'					
53-53	7/ 1/61	16°14'	155°56'					
53-54	7/ 1/61	16°17'	156°22'					
53-55	7/ 2/61	16°19'	156°54'					
53-56	7/ 2/61	16°43'	157°06'					
53-57	7/ 2/61	17°12'	157°11'					
53-58	7/ 2/61	17°42'	157°17'					
53-59	7/ 2/61	18°03'	157°21'					
53-60	7/ 2/61	18°32'	157°26'					
53-61	7/ 2/61	19°00'	157°31'					
53-62	7/ 3/61	19°59'	157°39'					
53-63	7/ 3/61	20°23'	157°43'	1	7/13/61	20°54'	156°53'	Lanai
				1	9/17/61	20°54'	156°53'	Lanai
53-64	7/ 3/61	20°31'	157°45'					
53-65	7/ 3/61	20°39'	157°46'					
53-66	7/ 3/61	20°47'	157°48'					
53-67	7/ 3/61	20°55'	157°48'					
53-68	7/ 3/61	21°03'	157°50'					
53-69	7/ 7/61	21°15'	157°57'					
53-70	7/ 7/61	21°09'	157°59'					
53-71	7/ 7/61	21°01'	158°02'					
53-72	7/ 7/61	20°52'	158°05'					
53-73	7/ 7/61	20°35'	158°10'					
53-74	7/ 7/61	20°27'	158°13'					
53-75	7/ 8/61	20°02'	158°27'					
53-76	7/ 8/63	19°11'	158°38'					
53-77	7/ 8/61	18°45'	158°46'					
53-78	7/ 8/61	18°28'	158°53'					
53-79	7/ 8/61	17°40'	159°10'					
53-80	7/ 9/61	16°57'	159°26'					
53-81	7/ 9/61	16°10'	159°37'					
53-82	7/ 9/61	16°05'	160°20'					
53-83	7/ 9/61	16°07'	161°18'					
53-84	7/10/61	16°00'	162°18'					
53-85	7/10/61	15°54'	163°11'					

CHARLES H. GILBERT CRUISE 53 - June 20 to July 30, 1961--Con.

Bottles (10 per batch) release batch no.	Release data			Recovery data				
	Date	Lat. (N.)	Long. (W.)	Number returns	Date	Lat. (N.)	Long. (W.)	Locality
53-86	7/10/61	15°59'	164°00'					
53-87	7/10/61	16°23'	164°32'					
53-88	7/11/61	17°19'	164°36'					
53-89	7/11/61	18°13'	164°41'					
53-90	7/11/61	19°06'	164°43'					
53-91	7/11/61	19°58'	164°49'					
53-92	7/12/61	20°55'	164°48'					
53-93	7/12/61	21°41'	164°40'					
53-94	7/12/61	22°29'	164°36'					
53-95	7/12/61	23°17'	164°36'					
53-96	7/13/61	24°02'	164°44'					
53-97	7/13/61	24°09'	165°49'					
53-98	7/14/61	23°53'	166°58'					
53-99	7/14/61	23°56'	167°50'					
53-100	7/15/61	23°55'	168°57'					
53-101	7/15/61	23°28'	169°21'					
53-102	7/15/61	22°35'	169°25'					
53-103	7/15/61	21°42'	169°28'					
53-104	7/16/61	20°58'	169°32'					
53-105	7/16/61	20°27'	169°38'					
53-106	7/16/61	19°21'	169°40'					
53-107	7/16/61	18°32'	169°35'					
53-108	7/17/61	17°46'	169°31'					
53-109	7/19/61	16°18'	169°32'					
53-110	7/19/61	16°02'	169°25'					
53-111	7/20/61	16°03'	168°41'					
53-112	7/20/61	16°03'	167°52'					
53-113	7/20/61	16°02'	167°06'					
53-114	7/20/61	16°53'	167°09'					
53-115	7/21/61	17°46'	167°11'					
53-116	7/21/61	18°35'	167°09'					
53-117	7/21/61	19°23'	167°07'					
53-118	7/21/61	20°16'	167°06'	1	9/ 7/61	26°04'	173°58'	Lisianski Island.
53-119	7/22/61	21°07'	167°08'					
53-120	7/22/61	22°01'	167°08'					
53-121	7/22/61	22°51'	167°02'					
53-122	7/22/61	23°19'	166°11'					
53-123	7/23/61	23°42'	165°24'					
53-124	7/23/61	23°58'	164°38'					
53-125	7/23/61	24°01'	163°42'					
53-126	7/23/61	24°04'	162°50'					
53-127	7/24/61	23°55'	162°02'					
53-128	7/24/61	22°59'	162°05'					
53-129	7/24/61	22°12'	162°08'					
53-130	7/24/61	21°20'	162°13'					
53-131	7/25/61	20°25'	162°15'					
53-132	7/25/61	19°32'	162°09'					
53-133	7/25/61	18°40'	162°06'					
53-134	7/25/61	17°39'	161°57'					
53-135	7/26/61	17°00'	161°39'					
53-136	7/26/61	16°59'	160°00'					
53-137	7/26/61	17°57'	160°00'					
53-138	7/27/61	18°57'	159°59'					
53-139	7/27/61	19°49'	159°56'					
53-140	7/27/61	20°42'	159°53'					
53-141	7/27/61	21°25'	159°54'					
53-142	7/27/61	21°29'	159°54'					
53-143	7/27/61	21°41'	159°55'					
53-144	7/27/61	21°51'	159°55'					
53-145	7/27/61	21°58'	159°54'					
53-146	7/27/61	22°06'	159°55'					
53-147	7/28/61	22°15'	159°55'					

Bottles (10 per batch) release batch no.	Release data			Recovery data				
	Date	Lat. (N.)	Long. (W.)	Number returns	Date	Lat. (N.)	Long. (W.)	Locality
53-148	7/28/61	22°15'	159°53'					
53-149	7/28/61	22°15'	159°50'					
53-150	7/28/61	22°24'	159°50'					
53-151	7/28/61	22°34'	159°50'					
53-152	7/28/61	22°43'	159°49'					
53-153	7/28/61	22°52'	159°49'					
53-154	7/28/61	23°01'	159°49'					
53-155	7/28/61	23°10'	159°49'					
53-156	7/28/61	23°38'	159°44'					
53-157	7/28/61	24°01'	159°37'					
53-158	7/28/61	24°03'	159°05'					
53-159	7/28/61	24°05'	158°35'					
53-160	7/28/61	24°06'	158°09'					
53-161	7/29/61	24°04'	157°43'					
53-162	7/29/61	24°02'	156°57'					
53-163	7/29/61	23°40'	157°06'					
53-164	7/29/61	23°32'	157°13'					
53-165*	7/29/61	23°25'	157°17'					
53-166	7/29/61	23°19'	157°20'					
53-167	7/29/61	23°12'	157°24'					
53-168	7/29/61	23°05'	157°28'					
53-169	7/29/61	22°58'	157°31'					
53-170	7/29/61	22°51'	157°33'					
53-171	7/29/61	22°45'	157°37'					
53-172	7/29/61	22°38'	157°40'					
53-173	7/29/61	22°30'	157°40'	2	8/14/61	22°03'	159°20'	Kauai
				1	8/23/61	22°05'	159°19'	Kauai
				1	8/13/61	22°05'	159°19'	Kauai
				1	8/12/61	22°14'	159°24'	Kauai
				1	8/15/61	22°11'	159°18'	Kauai
53-174	7/29/61	22°23'	157°40'					
53-175	7/30/61	22°14'	157°40'					
53-176	7/30/61	22°06'	157°40'					
53-177	7/30/61	21°59'	157°40'					
53-178	7/30/61	21°50'	157°39'	1	8/18/61	21°33'	157°51'	Oahu
				1	8/ 4/61	21°31'	157°50'	Oahu
				1	8/ 6/61	21°28'	157°48'	Oahu
				1	8/ 4/61	21°34'	157°53'	Oahu
53-179	7/30/61	21°42'	157°38'	1	8/ 4/61	21°35'	157°54'	Oahu
				1	8/ 8/61	21°29'	157°51'	Oahu
				1	8/ 2/61	21°37'	157°55'	Oahu
53-180	7/30/61	21°33'	157°36'	6	8/ 2/61	21°37'	157°55'	Oahu
				2	8/ 2/61	21°39'	157°56'	Oahu
				1	8/ 2/61	21°25'	157°44'	Oahu
53-181	7/30/61	21°25'	157°37'	1	7/30/61	21°24'	157°45'	Oahu
				14	7/31/61	21°24'	157°45'	Oahu
53-182	7/30/61	21°18'	157°38'	2	8/ 5/61	21°19'	157°39'	Oahu
				1	8/15/61	21°19'	157°39'	Oahu
				1	8/ 6/61	21°19'	157°39'	Oahu
				1	7/30/61	21°19'	157°39'	Oahu
				1	8/18/61	21°19'	157°39'	Oahu

* 20 bottles in lots from 53-165 to 182 inclusive.

M/V BROADBILL CRUISE 1 - Sept. 23 - Sept 27, 1961

Bottles (10 per batch) release batch no.	Release data			Recovery data				
	Date	Lat. (N.)	Long. (W.)	Number returns	Date	Lat. (N.)	Long. (W.)	Locality
Br-1	9/23/61	21°12'	157°49'					
Br-2	9/23/61	21°02'	157°47'					
Br-3	9/23/61	20°52'	157°45'					
Br-4	9/23/61	20°52'	157°48'					
Br-5	9/23/61	21°04'	157°50'					
Br-6	9/27/61	21°19'	158°12'					
Br-7	9/27/61	21°23'	158°25'					

CHARLES H. GILBERT CRUISE 54 - September 29 - December 4, 1961

Bottles (10 per batch) release batch no.	Release data			Recovery data				
	Date	Lat. (N.)	Long. (W.)	Number returns	Date	Lat. (N.)	Long. (W.)	Locality
54-1	9/29/61	21°09'	157°42'	1	10/ 9/61	21°24'	157°45'	Oahu
				1	10/12/61	21°24'	157°45'	Oahu
				1	10/11/61	21°28'	157°48'	Oahu
				1	10/10/61	21°28'	157°48'	Oahu
54-2	9/29/61	21°00'	157°44'	1	10/ 5/61	21°35'	157°54'	Oahu
54-3	9/29/61	20°50'	157°41'					
54-4	9/29/61	20°42'	157°37'					
54-5	9/29/61	20°34'	157°34'					
54-6	9/29/61	20°24'	157°28'					
54-7	9/30/61	20°00'	157°17'					
54-8	9/30/61	19°36'	157°07'					
54-9	9/30/61	19°10'	156°33'					
54-10	9/30/61	18°40'	156°46'					
54-11	9/30/61	18°26'	156°31'					
54-12	9/30/61	17°58'	156°53'					
54-13	9/30/61	17°35'	156°15'					
54-14	9/30/61	17°11'	156°05'					
54-15	10/ 1/61	16°47'	155°53'					
54-16	10/ 1/61	16°22'	155°40'					
54-17	10/ 1/61	15°34'	155°16'					
54-18	10/ 1/61	15°11'	155°04'					
54-19	10/ 1/61	14°46'	154°29'					
54-20	10/ 1/61	14°22'	154°37'					
54-21*	10/ 1/61	14°09'	154°32'					
54-22*	10/ 2/61	12°38'	154°34'					
54-23*	10/ 2/61	11°05'	152°36'					
54-24*	10/ 3/61	10°00'	151°21'					
54-25**	10/ 3/61	09°30'	151°04'					
54-26*	10/ 4/61	09°04'	150°27'					
54-27*	10/ 4/61	07°05'	149°17'					
54-28*	10/ 5/61	06°16'	148°07'					
54-29*	10/ 5/61	04°35'	147°02'					
54-30*	10/ 6/61	02°57'	146°11'					
54-31*	10/ 6/61	01°22'	145°21'					
54-32*	10/ 7/61	00°02'	144°32'					
54-33*	10/ 7/61	01°25'S	143°18'					
54-34***	10/ 8/61	02°57'S	143°03'					
54-35*	12/ 2/61	13°23'	157°45'					
54-36	12/ 2/61	14°17'	157°51'					
54-37	12/ 2/61	15°12'	157°54'					
54-38	12/ 2/61	15°40'	157°55'					
54-39	12/ 3/61	16°08'	157°55'					
54-40	12/ 3/61	16°35'	157°54'					

*40 per lot.
**37 bottles released in lot.
***20 bottles in lot.

CHARLES H. GILBERT CRUISE 54 - September 29 - December 4, 1961--Con.

Bottles (10 per batch) release batch no.	Release data			Recovery data				
	Date	Lat. (N.)	Long. (W.)	Number returns	Date	Lat. (N.)	Long. (W.)	Locality
54-41	12/ 3/61	17°06'	157°53'					
54-42	12/ 3/61	17°31'	157°55'					
54-43	12/ 3/61	17°59'	157°55'					
54-44	12/ 3/61	18°25'	157°55'					
54-45	12/ 3/61	18°55'	157°54'					
54-46	12/ 3/61	19°27'	157°50'					
54-47	12/ 4/61	19°36'	157°49'					
54-48	12/ 4/61	20°25'	157°51'					
54-49	12/ 4/61	20°35'	157°51'					
54-50	12/ 4/61	20°45'	157°52'					
54-51	12/ 4/61	20°51'	157°52'					
54-52	12/ 4/61	20°58'	157°50'					
54-53	12/ 4/61	21°04'	157°50'	2	12/26/61	22°03'	159°20'	Kauai
				1	1/ 1/62	22°03'	159°20'	Kauai
				1	12/28/61	21°58'	159°21'	Kauai
				1	1/ 7/62	22°03'	159°20'	Kauai
				2	12/27/61	22°00'	159°21'	Kauai

CHARLES H. GILBERT CRUISE 55 - January 15 - April 3, 1962

Bottles (10 per batch) release batch no.	Release data			Recovery data				
	Date	Lat. (N.)	Long. (W.)	Number returns	Date	Lat. (N.)	Long. (W.)	Locality
55-1	1/15/62	21°13'	157°56'					
55-2	1/15/62	21°05'	158°02'	1	1/18/62	21°17'	157°45'	Oahu
				4	1/18/62	21°18'	157°42'	Oahu
				1	1/24/62	21°16'	157°41'	Oahu
55-3	1/15/62	21°00'	158°09'	1	1/24/62	21°24'	157°45'	Oahu
55-4	1/15/62	20°54'	158°16'					
55-5	1/15/62	20°48'	158°23'					
55-6	1/15/62	20°42'	158°31'					
55-7	1/15/62	20°29'	158°46'					
55-8	1/16/62	20°10'	159°09'					
55-9	1/16/62	19°51'	159°32'					
55-10	1/16/62	19°31'	159°55'					
55-11	1/16/62	19°11'	160°20'					
55-12	1/16/62	18°55'	160°43'					
55-13	1/16/62	18°35'	161°09'					
55-14	1/16/62	18°16'	161°33'					
55-15	1/16/62	18°09'	161°51'					
55-16	1/17/62	17°52'	162°02'					
55-17	1/17/62	17°32'	162°24'					
55-18	1/17/62	17°12'	162°46'					
55-19	1/17/62	16°56'	163°05'					
55-20	1/17/62	16°38'	163°27'					
55-21	1/17/62	16°18'	163°48'					
55-22	1/17/63	15°58'	164°10'					
55-23	1/18/62	15°33'	164°38'					
55-24	1/18/62	15°17'	165°00'					
55-25	1/18/62	15°06'	165°15'					
55-26*	1/18/62	13°55'	166°55'					
55-27*	1/19/62	12°52'	168°01'					
55-28	1/19/62	12°22'	168°42'					
55-29*	1/19/62	11°47'	169°19'					
55-30*	1/20/62	10°36'	170°21'					
55-31*	1/20/62	09°21'	171°41'					
55-32*	1/21/62	08°16'	173°01'					
55-33*	1/21/62	07°10'	174°20'					

* 40 bottles per batch.

CHARLES H. GILBERT CRUISE 55 - January 15 - April 3, 1962--Con.

Bottles (10 per batch) release batch no.	Release data			Recovery data				
	Date	Lat. (N.)	Long. (W.)	Number returns	Date	Lat. (N.)	Long. (W.)	Locality
55-34*	1/22/62	06°18'	175°33'	1	8/18/62	07°31'	152°05'E	Onari Island
				1	4/ 6/62	07°10'	171°13'E	Ine Village, Arno Atoll
55-35*	1/22/62	05°12'	176°56'					
55-36*	1/23/62	04°06'	178°12'					
55-37*	1/23/62	02°52'	179°34'	1	4/11/62	05°19'	162°59'E	Tafunsak, Kusaie, E. Caroline Is.
				1	2/ 7/62	03°08'	172°54'E	Makin Atoll, Gilberts
55-38*	1/25/62	01°33'	179°01'E	1	4/21/62	01°24'S	138°45'E	St. Mathias, New Guinea
				1	6/ 2/62	07°25'	151°47'E	Epitar, Caroline Is.
55-39*	1/25/62	00°14'	177°44'E	11	2/ 2/62	00°55'	173°00'E	Maiana Is., Gilberts
				1	2/ 7/62	00°55'	173°00'E	Maiana Is., Gilberts
				1	2/28/62	00°55'	173°00'E.	Maiana Is., Gilberts
55-40*	1/26/62	00°56'S	176°22'E	1	10/10/62	07°47'S	156°22'E	Vella Lavella
				1	3/24/62	05°00'S	155°20'E	Green Island, New Guinea
				1	4/22/62	02°04'S	147°00'E	Nihau Is., Manus, New Guinea
				1	9/13/62	10°28'S	150°30'E	Finschhafen, New Guinea
55-41*	1/26/62	02°25'S	175°11'E	1	3/25/62	05°10'S	154°30'E	Bougainville, New Guinea
55-42*	1/27/62	03°27'S	173°10'E	1	9/22/62	11°25'S	152°00'E	Conflict Group Papua
				1	6/23/62	10°49'S	165°57'E	Nambalue, Santa Cruz Is.
55-43*	1/27/62	04°57'S	172°35'E	1	5/ 4/62	08°21'S	162°40'E	Sikaiana Is., Solomon Is.
55-44*	3/25/62	04°21'S	161°03'					
55-45*	3/25/62	03°53'S	160°39'					
55-46*	3/26/62	02°44'S	159°34'	1	6/24/63	01°43'S	142°54'E	Wuvulu Is.
55-47*	3/26/62	01°43'S	158°43'					
55-48*	3/27/62	00°25'	157°12'					
55-49*	3/28/62	01°06'	157°04'					
55-50*	3/29/62	03°06'	157°13'					
55-51*	3/30/62	05°40'	157°05'					
55-52*	3/30/62	07°20'	157°03'					
55-53*	3/31/62	09°05'	157°00'					
55-54*	3/31/62	10°50'	156°58'					
55-55*	4/ 1/62	12°35'	156°58'					
55-56*	4/ 1/62	14°29'	156°57'					
55-57	4/ 2/62	15°22'	157°03'					
55-58	4/ 2/62	15°47'	157°06'					
55-59	4/ 2/62	16°13'	157°09'					
55-60	4/ 2/62	16°39'	157°11'					
55-61	4/ 2/62	17°07'	157°15'					
55-62	4/ 2/62	17°36'	157°17'					
55-63	4/ 2/62	18°04'	157°22'					
55-64	4/ 2/62	18°32'	157°25'					
55-65	4/ 3/62	18°59'	157°31'					
55-66	4/ 3/62	19°26'	157°33'					
55-67	4/ 3/62	19°53'	157°38'					
55-68	4/ 3/62	20°02'	157°39'					
55-69	4/ 3/62	20°16'	157°41'					

* 40 bottles per batch.

CHARLES H. GILBERT CRUISE 55 - January 15 - April 3, 1962--Con.

Bottles (10 per batch) release batch no.	Release data			Recovery data				
	Date	Lat. (N.)	Long. (W.)	Number returns	Date	Lat. (N.)	Long. (W.)	Locality
55-70	4/ 3/62	20°19'	157°42'					
55-71	4/ 3/62	20°28'	157°44'					
55-72	4/ 3/62	20°38'	157°44'					
55-73	4/ 3/62	20°48'	157°44'	3	4/12/62	21°24'	157°43'	Oahu
55-74	4/ 3/62	20°58'	157°46'					
55-75	4/ 3/62	21°08'	157°49'	1	6/14/62	22°03'	159°20'	Kauai

CHARLES H. GILBERT CRUISE 56 - April 24 - May 12, 1962

Bottles (20 per batch) release batch no.	Release data			Recovery data				
	Date	Lat. (N.)	Long. (W.)	Number returns	Date	Lat. (N.)	Long. (W.)	Locality
56-1	4/24/62	21°10'	157°51'	5	4/26/62	21°17'	157°45'	Oahu
				1	6/ 5/62	21°17'	157°45'	Oahu
				1	4/26/62	21°16'	157°47'	Oahu
				1	5/30/62	22°05'	159°19'	Kauai
				1	4/25/62	21°18'	157°42'	Oahu
				1	4/26/62	21°18'	157°42'	Oahu
				1	5/ 3/62	21°17'	157°45'	Oahu
56-2	4/24/62	21°03'	157°51'	1	5/12/62	21°24'	157°45'	Oahu
				1	6/30/62	20°49'	156°59'	Lanai
				1	8/ 4/62	21°35'	158°17'	Oahu
56-3	4/24/62	20°55'	157°50'					
56-4	4/24/62	20°48'	157°50'	1	5/13/62	21°24'	157°45'	Oahu
				1	5/14/62	21°24'	157°45'	Oahu
56-5	4/24/62	20°41'	157°49'					
56-6	4/24/62	20°33'	157°49'					
56-7	4/25/62	20°10'	157°48'	1	5/13/62	20°03'	155°51'	Hawaii
				1	5/27/62	21°28'	157°48'	Oahu
56-8	4/25/62	19°50'	157°47'	1	5/27/62	19°34'	153°58'	Hawaii
56-9	4/25/62	19°29'	157°46'	1	5/19/62	20°53'	156°41'	Maui
				1	5/18/62	19°59'	155°50'	Hawaii
56-10	4/25/62	19°09'	157°45'					
56-11	4/25/62	18°47'	157°45'					
56-12	4/25/62	18°19'	157°47'					
56-13	4/25/62	17°53'	157°48'					
56-14	4/25/62	17°25'	157°50'					
56-15	4/26/62	17°01'	157°50'					
56-16	4/26/62	16°36'	157°50'					
56-17	4/26/62	16°11'	157°50'					
56-18	4/26/62	15°43'	157°51'					
56-19	4/26/62	15°17'	157°52'					
56-20	4/26/62	14°49'	157°53'					
56-21	5/11/62	16°01'	158°09'					
56-22	5/11/62	16°31'	158°14'					

CHARLES H. GILBERT CRUISE 57 - June 4 - June 25, 1962

Bottles (20 per batch) release batch no.	Release data			Recovery data				
	Date	Lat. (N.)	Long. (W.)	Number returns	Date	Lat. (N.)	Long. (W.)	Locality
57-1	6/ 4/62	21°07'	157°58'					
57-2	6/ 4/62	20°57'	157°58'					
57-3	6/ 4/62	20°42'	157°58'					
57-4	6/ 4/62	20°34'	157°58'					
57-5	6/ 4/62	20°26'	157°58'					
57-6	6/ 4/62	20°18'	157°58'					
57-7	6/ 4/62	20°03'	157°56'					
57-8	6/ 5/62	19°37'	157°57'	1	6/23/62	21°10'	156°43'	Molokai
	6/ 5/62	19°37'	157°57'	1	6/22/62	20°53'	156°41'	Maui
	6/ 5/62	19°37'	157°57'	1	6/27/62	20°49'	156°59'	Lanai
57-9	6/ 5/62	19°12'	157°56'					
57-10	6/ 5/62	18°48'	157°56'					
57-11	6/ 5/62	18°30'	157°55'					
57-12	6/ 5/62	18°07'	157°54'					
57-13	6/ 5/62	17°43'	157°52'					
57-14	6/ 5/62	17°20'	157°50'					
57-15	6/ 5/62	16°56'	157°48'					
57-16	6/ 6/62	16°25'	157°45'					
57-17	6/ 6/62	16°04'	157°43'					
57-18	6/ 6/62	15°37'	157°41'					
57-19	6/ 6/62	15°14'	157°39'					
Following lots consist of 40 drift bottles and 40 drift cards								
57-20*	6/25/62	19°29'	157°57'					
57-21	6/25/62	19°39'	157°56'					
57-22	6/25/62	19°49'	157°56'					
57-23	6/25/62	19°59'	157°55'					
57-24	6/25/62	20°08'	157°55'					
57-25	6/25/62	20°18'	157°54'	1	8/1/62	21°58'	159°43'	Kauai
57-26	6/25/62	20°28'	157°53'					
57-27	6/25/62	20°36'	157°52'					
57-28	6/25/62	20°54'	157°53'					
57-29	6/25/62	21°03'	157°54'					

* 40 bottles and 30 cards released.

CHARLES H. GILBERT CRUISE 58 - July 10 - July 19, 1962

Cards & bottles (100 per batch) release batch no.	Release data			Recovery data				
	Date	Lat. (N.)	Long. (W.)	Number returns	Date	Lat. (N.)	Long. (W.)	Locality
58-1*	7/10/62	21°21'	157°40'	1	7/13/62	21°19'	157°39'	Oahu
	7/10/62	21°21'	157°40'	6	7/11/62	21°19'	157°39'	
	7/10/62	21°21'	157°40'	23	7/11/62	21°20'	157°42'	Oahu
	7/10/62	21°21'	157°40'	4	7/13/62	21°20'	157°42'	
	7/10/62	21°21'	157°40'	4	7/12/62	21°21'	157°42'	
	7/10/62	21°21'	157°40'	3	7/15/62	21°20'	157°42'	
	7/10/62	21°21'	157°40'	2	7/14/62	21°20'	157°42'	
	7/10/62	21°21'	157°40'	1	7/22/62	21°20'	157°42'	
	7/10/62	21°21'	157°40'	1	7/16/62	21°22'	157°42'	Oahu
	7/10/62	21°21'	157°40'	1	7/11/62	21°22'	157°42'	
58-2*	7/10/62	21°26'	157°42'	1	7/11/62	21°24'	157°43'	Oahu
	7/10/62	21°26'	157°42'	1	7/10/62	21°24'	157°45'	Oahu
	7/10/62	21°26'	157°42'	71	7/11/62	21°24'	157°45'	
	7/10/62	21°26'	157°42'	7	7/12/62	21°24'	157°45'	

* 100 cards and 100 bottles.

CHARLES H. GILBERT CRUISE 58 - July 10 - July 19, 1962--Con.

Cards & bottles (100 per batch) release batch no.,	Release data			Recovery data				
	Date	Lat. (N.)	Long. (W.)	Number returns	Date	Lat. (N.)	Long. (W.)	Locality
58-3**	7/10/62	21°32'	157°48'	1	7/16/62	21°43'	157°59'	Oahu
	7/10/62	21°32'	157°48'	1	7/12/62	21°35'	157°54'	Oahu
	7/10/62	21°32'	157°48'	1	8/ 4/62	21°39'	157°56'	Oahu
	7/10/62	21°32'	157°48'	38	7/11/62	21°39'	157°56'	
	7/10/62	21°32'	157°48'	26	7/12/62	21°39'	157°56'	
	7/10/62	21°32'	157°48'	38	7/11/62	21°37'	157°55'	Oahu
	7/10/62	21°32'	157°48'	4	7/12/62	21°37'	157°55'	
	7/10/62	21°32'	157°48'	5	7/13/62	21°37'	157°55'	
	7/10/62	21°32'	157°48'	1	7/15/62	21°37'	157°55'	
58-4***	7/10/62	21°40'	157°53'	1	3/6/63	27°55'	174°44'	Pearl & Hermes Reef
	7/10/62	21°40'	157°53'	1	7/11/62	21°39'	157°56'	Oahu
	7/10/62	21°40'	157°53'	1	7/14/62	21°36'	158°06'	Oahu
	7/10/62	21°40'	157°53'	1	7/21/62	21°43'	157°59'	Oahu
	7/10/62	21°40'	157°53'	1	7/16/62	21°43'	157°59'	Oahu
	7/10/62	21°40'	157°53'	1	7/18/62	21°43'	157°59'	
	7/10/62	21°40'	157°53'	1	7/22/62	21°43'	157°59'	

**100 cards and 120 bottles.
***100 cards and 160 bottles.

CHARLES H. GILBERT CRUISE 59 - July 23 - August 15, 1962

Cards (20 per batch) release batch no.	Release data			Recovery data				
	Date	Lat. (N.)	Long. (W.)	Number returns	Date	Lat. (N.)	Long. (W.)	Locality
59-1	7/23/62	21°08'	157°52'					
59-2	7/23/62	20°58'	157°53'					
59-3	7/23/62	20°39'	157°53'					
59-4	7/23/62	20°38'	157°55'					
59-5	7/23/62	20°31'	157°54'					
59-6	7/23/62	20°22'	157°53'					
59-7	7/23/62	19°57'	157°52'					
59-8	7/23/62	19°28'	157°53'					
59-9	7/24/62	18°59'	157°52'					
59-10	7/24/62	18°29'	157°49'					
59-11	7/24/62	18°03'	157°48'					
59-12	7/24/62	17°36'	157°48'					
59-13	7/24/62	17°11'	157°49'					
59-14	7/24/62	16°45'	157°49'					
59-15	7/24/62	16°19'	157°48'					
59-16	7/24/62	16°00'	151°47'					
59-17	7/24/62	15°34'	157°48'					
59-18	7/24/62	15°07'	157°49'					
59-19	8/15/62	20°41'	158°02'					
59-20	8/15/62	20°50'	157°59'					
59-21	8/15/62	21°02'	157°56'					
59-22	8/15/62	21°08'	157°53'					

CHARLES H. GILBERT CRUISE 60 - September 26 - October 12, 1962

Cards & bottles (10 per batch) release batch no.	Release data			Recovery data				
	Date	Lat. (N.)	Long. (W.)	Number returns	Date	Lat. (N.)	Long. (W.)	Locality
60-1	9/29/62	19°29'	155°59'					
60-2	9/30/62	19°30'	156°02'					
60-3	9/30/62	19°28'	156°02'					
60-4	9/30/62	19°29'	156°01'					
60-5	9/30/62	19°31'	156°00'					
60-6	10/ 1/62	19°35'	156°00'					
60-7	10/ 1/62	19°38'	156°02'					
60-8	10/ 1/62	19°44'	156°06'					
60-9	10/ 1/62	19°47'	156°05'					
60-10	10/ 3/62	19°33'	156°00'					
60-11	10/ 3/62	19°33'	156°00'					
60-12	10/ 4/62	19°34'	156°01'					
60-13	10/ 4/62	19°28'	156°02'					
60-14	10/ 5/62	19°14'	156°05'					
60-15	10/ 5/62	19°07'	156°04'					
60-16	10/ 5/62	19°11'	155°59'					
60-17*	10/ 5/62	19°15'	155°57'					
60-18	10/ 6/62	19°07'	156°04'					
60-19	10/ 7/62	19°20'	155°57'					
60-20	10/ 7/62	19°25'	156°00'					
60-21	10/ 7/62	19°38'	156°04'					
60-22	10/ 9/62	19°04'	156°03'					
60-23	10/ 9/62	19°05'	155°57'					
60-24	10/10/62	19°04'	155°56'					
60-25	10/10/62	19°05'	155°56'					
60-26	10/10/62	19°04'	155°57'					
60-27	10/11/62	19°02'	155°59'					
60-28	10/11/62	19°06'	156°02'					

* 20 cards released.

CHARLES H. GILBERT CRUISE 63 - January 10 - March 2, 1963

Cards & bottles (20 ea. per batch) release batch no.	Release data			Recovery data				
	Date	Lat. (N.)	Long. (W.)	Number returns	Date	Lat. (N.)	Long. (W.)	Locality
63-1*	1/10/63	21°17'	157°52'					
63-2	1/10/63	21°06'	157°42'	1	3/22/63	21°22'	157°42'	Oahu(Bellows)
				1	1/26/63	21°19'	157°53'	Oahu(Ft.Kam)
				1	2/13/63	21°06'	157°10'	Molokai
				1	3/ 3/63	21°06'	157°14'	Molokai
63-3	1/10/63	20°59'	157°37'					
63-4	1/10/63	20°52'	157°30'	1	2/ 9/63	20°49'	156°59'	Lanai
63-5	1/10/63	20°44'	157°24'					
63-6	1/10/63	20°38'	157°19'					
63-7**	1/11/63	19°05'	155°59'					
63-8	1/11/63	18°58'	155°52'					
63-9	1/11/63	18°35'	155°18'					
63-10	1/11/63	18°00'	154°30'					
63-11	1/12/63	17°24'	153°36'					
63-12	1/12/63	16°54'	151°54'					
63-13	1/12/63	15°48'	151°18'					
63-14	1/13/63	15°18'	150°30'					
63-15	1/14/63	20°47'	149°50'					
63-16	1/15/63	20°49'	150°02'					
63-17	1/17/63	18°04'	149°46'					

* Releases 63-1 through 63-6 = 20 cards and 20 bottles each.
** Releases 63-7 through 63-28 = 20 cards.

CHARLES H. GILBERT CRUISE 63 - January 10 - March 2, 1963--Con.

Cards & bottles (20 ea. per batch) release batch no.	Release data			Recovery data				
	Date	Lat. (N.)	Long. (W.)	Number returns	Date	Lat. (N.)	Long. (W.)	Locality
63-18	1/18/63	17°50'	149°47'					
63-19	1/22/63	15°57'	149°47'					
63-20	2/ 6/63	18°09'	149°49'					
63-21	2/ 9/63	15°16'	149°51'					
63-22	2/11/63	15°15'	150°09'					
63-23	2/15/63	23°05'	150°08'					
63-24	2/16/63	23°07'	149°55'					
63-25	2/17/63	23°05'	150°03'					
63-26	2/20/63	20°45'	149°50'					
63-27	2/22/63	20°36'	149°56'					
63-28	2/23/63	20°38'	149°51'					

USC&GS SURVEYOR - February 25 - March 4, 1963

Cards (20 per batch) release batch no.	Release data			Recovery data				
	Date	Lat. (N.)	Long. (W.)	Number returns	Date	Lat. (N.)	Long. (W.)	Locality
S-1*	2/25/63	29°56'	180°00'					
S-2*	2/25/63	30°13'	180°00'					
S-3	2/25/63	30°43'	180°00'					
S-4	2/25/63	31°06'	180°00'					
S-5	2/25/63	31°33'	180°00'					
S-6	2/26/63	32°12'	180°00'					
S-7	2/26/63	32°42'	180°00'					
S-8	2/26/63	33°11'	180°00'					
S-9	2/26/63	33°37'	180°00'					
S-10	2/26/63	34°12'	180°00'					
S-11	2/26/63	34°33'	180°00'					
S-12	2/26/63	35°00'	180°00'					
S-13	2/26/63	35°42'	180°00'					
S-14	2/26/63	36°08'	180°00'					
S-15	2/26/63	36°42'	180°00'					
S-16	2/26/63	37°13'	180°00'					
S-17	2/26/63	37°06'	180°00'					
S-18	2/27/63	38°17'	180°00'					
S-19	2/27/63	39°12'	180°00'					
S-20	2/27/63	39°24'	180°00'					
S-21	2/27/63	39°48'	180°00'					
S-22	2/27/63	39°36'	179°48'					
S-23	2/27/63	39°08'	180°00'					
S-24	2/27/63	39°05'	180°00'					
S-25	2/27/63	38°44'	180°00'					
S-26	2/27/63	38°01'	180°00'					
S-27	2/27/63	37°40'	180°00'					
S-28	2/27/63	37°18'	180°00'					
S-29	2/27/63	36°59'	179°48'					
S-30	2/28/63	36°29'	179°47'					
S-31	2/28/63	36°00'	179°47'					
S-32	2/28/63	35°28'	179°48'					
S-33	2/28/63	35°06'	179°48'					
S-34	2/28/63	34°38'	179°28'					
S-35	2/28/63	34°42'	179°48'					
S-36	2/28/63	33°56'	179°48'					
S-37	2/28/63	33°35'	179°48'					
S-38	2/28/63	33°04'	179°48'					
S-39	2/28/63	32°48'	179°48'					
S-40	2/28/63	32°09'	179°48'					

* 5 cards released in lot.

USC&GS SURVEYOR - February 25 - March 4, 1963--Con.

Cards (20 per batch) release batch no.	Release data			Recovery data				
	Date	Lat. (N.)	Long. (W.)	Number returns	Date	Lat. (N.)	Long. (W.)	Locality
S-41	2/28/63	31°41'	179°48'					
S-42	3/ 1/63	31°13'	179°48'					
S-43	3/ 1/63	29°43'	179°48'					
S-44	3/ 1/63	30°15'	179°48'					
S-45	3/ 3/63	30°20'	179°48'					
S-46	3/ 3/63	30°50'	179°48'					
S-47	3/ 3/63	31°21'	179°48'					
S-48	3/ 3/63	31°59'	179°48'					
S-49	3/ 3/63	32°42'	179°48'					
S-50	3/ 3/63	32°48'	179°48'					
S-51	3/ 3/63	33°48'	179°48'					
S-52	3/ 3/63	33°08'	179°48'					
S-53	3/ 3/63	34°22'	179°48'					
S-54	3/ 3/63	34°53'	179°48'					
S-55	3/ 3/63	35°26'	179°48'					
S-56	3/ 3/63	35°36'	179°48'					
S-57	3/ 4/63	36°17'	179°48'					
S-58	3/ 4/63	36°41'	179°48'					
S-59	3/ 4/63	37°12'	179°48'					
S-60	3/ 4/63	37°38'	179°48'					
S-61	3/ 4/63	38°45'	179°48'					

USC&GS SURVEYOR - March 29 - April 17, 1963

Cards (20 per batch) release batch no.	Release data			Recovery data				
	Date	Lat. (N.)	Long. (W.)	Number returns	Date	Lat. (N.)	Long. (W.)	Locality
S-62	3/29/63	30°02'	170°46'					
S-63	3/30/63	30°31'	170°46'					
S-64	3/30/63	31°02'	170°46'					
S-65	3/30/63	31°30'	170°47'					
S-66	3/30/63	32°02'	170°48'					
S-67	3/30/63	32°36'	170°47'					
S-68	3/30/63	33°06'	170°47'					
S-69	3/30/63	33°36'	170°48'					
S-70	3/30/63	34°06'	170°48'					
S-71	3/30/63	34°21'	170°48'					
S-72	3/30/63	34°36'	170°48'					
S-73	3/30/63	35°05'	170°48'					
S-74	3/30/63	35°09'	170°48'					
S-75	3/31/63	36°24'	170°48'					
S-76	3/31/63	36°48'	170°48'					
S-77	3/31/63	37°07'	170°48'					
S-78	3/31/63	37°32'	170°48'					
S-79	3/31/63	38°00'	170°48'					
S-80	3/31/63	38°06'	170°48'					
S-81	3/31/63	39°06'	170°51'					
S-82	3/31/63	39°30'	170°51'					
S-83	3/31/63	39°50'	170°52'					
S-84	3/31/63	39°50'	171°03'					
S-85	4/15/63	38°06'	172°09'					
S-86	4/15/63	38°04'	172°18'					
S-87	4/16/63	37°50'	172°18'					
S-88	4/16/63	37°24'	172°18'					
S-89	4/16/63	36°54'	172°18'					
S-90	4/16/63	36°36'	172°17'					
S-91	4/16/63	35°54'	172°16'					
S-92	4/16/63	35°24'	172°15'					
S-93	4/16/63	34°55'	172°14'					
S-94	4/16/63	34°25'	172°13'					

USC&GS SURVEYOR - March 29 - April 17, 1963--Con.

Cards (20 per batch) release batch no.	Release data			Recovery data				
	Date	Lat. (N.)	Long. (W.)	Number returns	Date	Lat. (N.)	Long. (W.)	Locality
S-95	4/16/63	34°00'	172°13'					
S-96	4/16/63	34°30'	172°12'					
S-97	4/16/63	33°00'	172°12'					
S-98	4/16/63	32°30'	172°12'					
S-99	4/16/63	32°01'	172°10'					
S-100	4/17/63	31°01'	172°07'					
S-101	4/17/63	30°30'	172°07'					

CHARLES H. GILBERT CRUISE 64 - April 9-14 and April 24-29, 1963

Cards (20 per batch) release batch no.	Release data			Recovery data				
	Date	Lat. (N.)	Long. (W.)	Number returns	Date	Lat. (N.)	Long. (W.)	Locality
64-1	4/ 9/63	21°19'	158°07'	1	6/22/63	21°17'	157°42'	Oahu
64-2	4/ 9/63	21°05'	158°15'					
64-3	4/ 9/63	20°52'	158°29'					
64-4	4/ 9/63	20°40'	158°43'					
64-5	4/ 9/63	20°26'	158°56'					
64-6	4/10/63	20°14'	159°10'					
64-7	4/10/63	20°06'	159°09'					
64-8	4/10/63	20°03'	158°51'					
64-9	4/10/63	20°03'	158°34'					
64-10	4/10/63	20°04'	158°16'					
64-11	4/10/63	20°03'	158°13'					
64-12	4/10/63	19°55'	158°29'					
64-13	4/10/63	20°30'	158°32'					
64-14	4/11/63	20°10'	158°17'					
64-15	4/11/63	20°31'	158°17'					
64-16	4/11/63	20°09'	158°18'					
64-17	4/11/63	20°10'	158°36'					
64-18	4/11/63	20°28'	158°43'					
64-19	4/11/63	20°32'	158°31'					
64-20	4/11/63	20°32'	158°31'					
64-21	4/12/63	20°12'	158°25'					
64-22	4/12/63	20°08'	158°42'					
64-23	4/12/63	20°09'	158°46'					
64-24	4/12/63	20°11'	158°31'					
64-25	4/13/63	20°01'	158°50'					
64-26	4/13/63	20°01'	158°50'					
64-27	4/13/63	19°51'	158°40'					
64-28	4/13/63	20°09'	158°38'					
64-29	4/13/63	20°24'	158°33'					
64-30	4/14/63	20°08'	158°41'					
64-31	4/14/63	20°22'	158°12'					
64-32	4/14/63	20°31'	158°09'					
64-33	4/14/63	20°39'	158°06'					
64-34	4/14/63	20°50'	158°03'					
64-35	4/26/63	21°05'	158°08'					
64-36	4/26/63	20°53'	158°23'					
64-37	4/26/63	20°41'	158°12'					
64-38	4/26/63	20°45'	158°30'					
64-39	4/26/63	20°48'	158°50'					
64-40	4/26/63	20°39'	158°35'					
64-41	4/26/63	20°32'	158°21'					
64-42	4/27/63	20°35'	158°41'					
64-43	4/27/63	20°31'	158°45'					
64-44	4/27/63	20°23'	158°30'					
64-45	4/27/63	20°21'	158°48'					
64-46	4/27/63	20°15'	158°58'					
64-47	4/27/63	20°10'	158°41'					

CHARLES H. GILBERT CRUISE 64 - April 9-14 and April 24-29, 1963--Con.

Cards (20 per batch) release batch no.	Release data			Recovery data				
	Date	Lat. (N.)	Long. (W.)	Number returns	Date	Lat. (N.)	Long. (W.)	Locality
64-48	4/27/63	20°10'	158°51'					
64-49	4/27/63	20°10'	158°53'					
64-50	4/27/63	20°10'	158°54'					
64-51	4/28/63	20°11'	158°52'					
64-52	4/28/63	20°10'	158°56'					
64-53	4/28/63	20°10'	158°55'					
64-54	4/28/63	20°09'	158°55'					
64-55	4/28/63	20°09'	158°56'					
64-56	4/28/63	20°09'	158°57'					
64-57	4/29/63	20°10'	158°56'					

USC&GS SURVEYOR - May 7 - May 15, 1963

Cards (20 per batch) release batch no.	Release data			Recovery data				
	Date	Lat. (N.)	Long. (W.)	Number returns	Date	Lat. (N.)	Long. (W.)	Locality
S-102	5/ 7/63	30°00'	180°00'					
S-103	5/ 7/63	30°36'	179°24'					
S-104	5/ 7/63	30°54'	178°54'					
S-105	5/ 7/63	31°18'	178°36'					
S-106	5/ 8/63	31°42'	178°02'					
S-107	5/ 8/63	32°00'	177°08'					
S-108	5/ 8/63	32°24'	177°24'					
S-109	5/ 8/63	32°36'	177°47'					
S-110	5/ 8/63	32°54'	178°12'					
S-111	5/ 8/63	33°00'	178°03'					
S-112	5/ 8/63	33°18'	178°48'					
S-113	5/ 8/63	33°36'	179°21'					
S-114	5/ 8/63	33°54'	179°48'					
S-115	5/ 8/63	34°00'	180°00'					
S-116	5/ 8/63	34°06'	179°07'					
S-117	5/11/63	34°02'	180°00'					
S-118	5/11/63	35°00'	180°00'					
S-119	5/12/63	36°00'	180°00'					
S-120	5/13/63	36°07'	179°43'					
S-121	5/13/63	36°36'	179°24'					
S-122	5/13/63	37°00'	179°06'					
S-123	5/13/63	37°24'	178°36'					
S-124	5/14/63	37°54'	178°42'					
S-125	5/14/63	38°00'	178°00'					
S-126	5/14/63	38°42'	177°30'					
S-127	5/14/63	39°00'	177°06'					
S-128	5/15/63	39°12'	176°55'					
S-129	5/15/63	38°54'	177°00'					
S-130	5/15/63	39°24'	177°24'					
S-131	5/15/63	39°42'	178°00'					
S-132	5/15/63	39°42'	178°49'					
S-133	5/15/63	39°48'	179°18'					
S-134	5/15/63	40°00'	180°00'					
S-135	5/15/63	40°05'	179°55'					
S-136	5/15/63	40°12'	179°30'					
S-137	5/15/63	40°54'	179°12'					
S-138	5/15/63	41°18'	178°54'					
S-139	5/15/63	41°50'	178°30'					

CHARLES H. GILBERT CRUISE 66 - June 7 - June 23, 1963

Cards (20 per batch) release batch no.	Release data			Recovery data				
	Date	Lat. (N.)	Long. (W.)	Number returns	Date	Lat. (N.)	Long. (W.)	Locality
66-1	6/ 8/63	21°14'	153°33'					
66-2	6/ 9/63	20°21'	153°26'					
66-3	6/ 9/63	19°26'	153°22'					
66-4	6/ 9/63	18°58'	153°21'					
66-5	6/ 9/63	18°30'	153°26'					
66-6	6/ 9/63	18°02'	153°24'					
66-7	6/ 9/63	17°35'	153°18'					
66-8	6/ 9/63	17°08'	153°17'					
66-9	6/10/63	16°40'	153°16'					
66-10	6/10/63	16°13'	153°16'					
66-11	6/10/63	15°55'	153°25'					
66-12	6/10/63	15°30'	153°24'					
66-13	6/10/63	16°00'	153°26'					
66-14	6/11/63	16°02'	153°22'					
66-15	6/12/63	16°08'	153°18'					
66-16	6/12/63	16°07'	153°16'					
66-17	6/13/63	16°10'	153°15'					
66-18	6/13/63	16°11'	153°14'					
66-19	6/14/63	16°18'	153°12'					
66-20	6/15/63	16°27'	153°08'					
66-21	6/16/63	16°41'	152°58'					
66-22	6/17/63	16°41'	153°01'					
66-23	6/17/63	16°20'	153°12'					
66-24	6/17/63	16°20'	153°12'					
66-25	6/18/63	15°27'	153°14'					
66-26	6/18/63	15°15'	153°14'					

MS #1392

UNITED STATES
DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
BUREAU OF COMMERCIAL FISHERIES
WASHINGTON, D.C. 20240

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26. Observations of Fish from a Floating Observation Raft at Sea

Pelagic fishes are frequently seen congregating around floating objects at sea. The ecology and behavior of fish accumulating around a drifting raft with a viewing chamber were observed near the island of Hawaii for a total of 85 daylight hours during five drifts of up to 50 hours' duration. A modified version of this raft was taken south to the Equator where two drifts of 8 and 9 days were made.

Nineteen identified species of fish and one species of porpoise were seen from the chamber near Hawaii. They were classified into three groups—transients, visitors and residents—on the basis of their reaction to the raft and the length of time they remained. Transients included *Decapterus* sp., *Euthynnus pelamis*, and istiophorids; they demonstrated no apparent attraction to the raft. Visitors included *Sphyraena barracuda*, *Pterolamiops longimanus*, *Manta alfredi*, and porpoise. They came to the raft and swam around for a few minutes before leaving. Residents included *Canthidermis maculatus*, *Coryphaena hippurus*, *Psenes cyanophrys*, *Acanthocybium solandri*, *Decapterus* sp., *Seriola* sp. and juvenile *Abudefduf abdominalis*. *P. cyanophrys* was the first to appear on all drifts and had the highest rate of increase.

Total numbers of residents increased three times faster when the raft was drifting than when it was anchored and ten times faster during daylight than at night. *Seriola* sp. was the only predator at the raft which successfully preyed on smaller fishes present. *C. maculatus*, *P. cyanophrys*, *A. abdominalis*, *and Caranx kalla* took shelter near the raft when they were frightened by other fish, approaching boats, or other disturbances. Observations of a *C. maculatus* picking a parasitic isopod from another and attempting to pick from *C. hippurus* and *Decapterus* indicate that apparently *C. maculatus* is a parasite picker and that floating objects may be pelagic cleaning stations.

On the two drifts near the Equator the following animals were seen from the observation chamber: adult and juvenile *E. pelamis*, small adult and juvenile *Neothunnus macropterus*, *A. solandri*, adult *C. hippurus*, adult and juvenile *Coryphaena equiselis*, *Decapterus pinnulatus*, *Elagatis bipinnulatus*, *Psenes cyanophrys*, *P. longimanus*, *Prionace glauca*, *Rhincodon typus*, *Manta* sp., *Naucrates ductor*, *Remora* sp., Exocoetidae, turtle and porpoise.

In general, accumulations at the raft had properties ascribed to a community with species playing different interwoven roles.

REGINALD M. GOODING
U. S. Bureau of Commercial Fisheries

1964. [Abstract] Proceedings of the Hawaiian Academy of Science. 39th Annual Meeting, 1963-1964, p. 27.

24. Activity Patterns of Scombrids

Scombrid fishes are characterized by continuous swimming. This is associated in various degrees with search for food, gill ventilation, and maintenance of hydrostatic equilibrium. These three functional aspects of swimming are being investigated by studies of the activity patterns of scombrids in shoreside tanks (24 feet in diameter, and 3 feet deep) at Kewalo Basin.

Quantitative data on activity, measured as swimming speed, are obtained from an observation window in a tower overlooking the tanks. A Plexiglass board, parallel to the tank's surface, is inserted into the frame of the observation window. Sheets of clear plastic acetate paper are laid over the board and the path of the fish swimming in the tank is traced by an observer onto the acetate sheet with a wax pencil. While tracing, the observer views the tank from a fixed position through the acetate paper and Plexiglass. The length of the path, traced over a known time interval, is measured from the paper with a map measurer and converted to distance traveled by the fish and swimming speed. The distances between the window, the tank, and the observer's eye determine the conversion factor. In the present situation, 1 cm. on the acetate paper equals 24 cm. in the tank.

Wavyback skipjack, *Euthynnus yaito* Kishinouye, which have been in the tank for a month or so, swim at the same slow speed (about 0.9 m/sec for a 0.4 m. fork-length fish) throughout the day and night in the absence of food stimuli. If deprived of food for several days, speed decreases to about 0.6 m/sec, only to increase again following a meal. The average density of five intact *E. yaito* was 1.074 gm/cc, their food 1.071 gm/cc, and their sea water environment 1.024 gm/cc. Based on these density measurements, a 1 kg. *E. yaito* would weigh about 50 gm. in sea water and would tend to sink. Following a meal of 100 gm., its weight in water would increase by about 5 gm., because the food was also more dense than sea water. Since these fish swam faster when their stomachs were full and since they received lift while swimming from the planing action of their pectoral fins, it appears that the increase in speed following a meal results in part from the increase in weight.

Another adaptation to maintain hydrostatic equilibrium is the swim bladder. This organ is absent in *E. yaito* and in many other scombrids. All scombrids without swim bladders are relatively small species, less than 30 kg. in maximum recorded weight, whereas at least eight of those species with swim bladders attain sizes in excess of 30 kg.; some grow over 100 kg. A 100 kg. tuna without a swim bladder would weigh about 5,000 gm. in water if it had the same density as *E. yaito*. It can be speculated that the planing action of pectoral fins can be sufficient for the amount of lift required by smaller species, but that additional adaptations such as swim bladders are necessary for species with greater mass and heavier weights in water.

Analyses such as those presented in this abstract are being conducted on the activity patterns of scombrids to determine the effects of the functional components of locomotion on their behavior.

JOHN J. MAGNUSON
U. S. Bureau of Commercial Fisheries

1964. /Abstract/ Proceedings of the Hawaiian Academy of Science. 39th Annual Meeting, 1963-1964, p. 26.

Tuna Behaviour Research Programme at Honolulu

Abstract

The behaviour research programme of the Biological Laboratory of the U.S. Bureau of Commercial Fisheries at Honolulu is conducting studies of the sensory abilities and the behaviour of tuna. The methodologies of the comparative psychologist and ethologist are being utilised to gain a basic understanding of the ways in which a tuna responds to its environment. At present, detection of underwater sound, feeding behaviour, social behaviour, vision, and the changes in behaviour throughout the day are being investigated. These studies are conducted at sea using underwater viewing ports in the research vessel *Charles H. Gilbert* and in a floating raft, *Nenue I*, and in eight shoreside tanks at Kewalo Basin, Honolulu.

Le programme de recherche, à Honolulu, sur le comportement du thon.

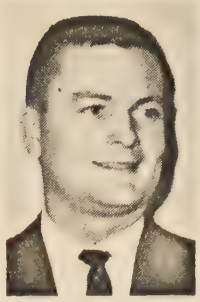
Résumé

Dans le cadre du programme de recherche sur le comportement du poisson, le Laboratoire biologique de l'U.S. Bureau of Commercial Fisheries à Honolulu, conduit actuellement des études sur les facultés sensorielles et le comportement des thons. Les méthodologies de psychologie et d'éthologie comparatives ont été utilisées pour arriver à une base de compréhension de la façon dont réagit le thon à son environnement. Jusqu'à ce jour, la vision, la détection des sons sous-marins, l'habitude alimentaire, le comportement social et les changements de comportement durant la journée ont été observés. Ces études ont été conduites en mer, à travers des hublots sous-marins montés dans la coque du bateau de recherche *Charles H. Gilbert*, sur un radeau flottant, le *Nenue I*, et dans hit bassins à Kewalo Basin, Honolulu.

Programa de investigaciones del comportamiento del atún en Honolulu

Extracto

Como parte del programa de investigaciones del comportamiento del atún, el Laboratorio de Biología de la Oficina de Pesca Industrial de los E.U.A. en Honolulu, estudia la capacidad sensorial con relación al comportamiento. Se emplea la metodología de la sicología y etiología comparativas para tener un conocimiento básico de la manera en que el atún reacciona ante su ambiente. Actualmente se investigan la vista, la determinación de los sonidos subacuáticos, el comportamiento durante la alimentación y en sus relaciones con otros miembros del cardumen y los cambios del comportamiento durante el día. Estos estudios se realizan en la mar empleando los portillos submarinos del buque investigador *Charles H. Gilbert*, en una balsa flotante *Nenue I* y en ocho estanques en la costa en Kewalo Basin, Honolulú.



by

John J. Magnuson

Bureau of Commercial Fisheries, Hawaii

TUNA behaviour studies are one of eight major research endeavours of the Biological Laboratory of the U.S. Bureau of Commercial Fisheries at Honolulu. The objective of the behaviour research is to gain a basic understanding of the behaviour and the sensory abilities of tuna. An understanding of tuna behaviour is expected to be useful in the future design of fishing gear and fishing methods and in locating tuna.

The research programme was originally conceived in 1957 as a study of stimuli which attracted or repelled tuna to or from pole-and-line tuna fishing boats. Between 1958 and the present the orientation of the research has slowly changed toward a more general query with the potential of more generalised application.

Both a sea phase and a shore phase were begun in 1958. The first problem of each was to develop methods of studying the fast swimming pelagic tunas. Progress in these efforts was reported for the sea phase by Strasburg and Yuen (1960)[4] and for the shore phase by Nakamura (1962)[3]. By 1960 the oceanographic research vessel *Charles H. Gilbert* had been equipped with stern and bow underwater viewing ports, and feeding behaviour of tuna had been observed and photographed at sea. By 1961 the skipjack, *Euthynnus pelamis*, had successfully been kept and studied in shoreside tanks at Kewalo Basin, Honolulu, for almost six months. In 1962 a 12 ft by 12 ft raft with a viewing chamber beneath it was

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While a large body of information has been accumulated there are still many unknowns concerning the detailed behaviour responses of fish, both to natural environmental, and to artificial influences. This is largely due to the difficulties of observing fish in the sea directly. The recent development of high resolution echo sounders and techniques of underwater observation, and the growth of experimental aquarium work have, however, provided basic information. Work involving personal observation of fish in the sea, under varying environmental conditions and throughout the diurnal light cycle, is needed in order to confirm the pointers obtained from aquarium studies and by applying less direct methods. The need for appropriate underwater vehicles or chambers, for conveying observers to depths up to 80-100 fathoms, cannot be too strongly stressed. The use in the U.S.S.R. of a submarine with observation windows for this purpose is especially interesting.[7]

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designed and built by R. Gooding and was successfully used as a passive observation platform to observe and photograph dolphin fish, *Coryphaena hippurus*, and other large predators at sea. By the end of 1962, a total of eight tanks had been designed and erected for specific investigations at Kewalo Basin. In 1963 these facilities are being used by six biologists and aides engaged in analysing the enigmas of tuna's behaviour.

Two types of study are being conducted, those of sensory ability and those of behaviour. The methodologies of the comparative psychologist and the ethologist are being applied to species whose ways have long been observed by fishermen. Application of these methods is increasing the rate at which understanding of tuna behaviour increases.

Both visual and hearing abilities are being quantified with captive tuna at Kewalo Basin. The tuna are taught to associate an underwater sound or image with food or, in some cases, an electric shock. After training is completed, the tuna reacts to the visual or sound stimulus in the absence of the food or electric shock. The conditioned response indicates that the sound or image was perceived by the tuna's sensory system. A careful choice of stimuli make it possible to describe the ability of the sensory system to perceive the environment in standardised and generalised terms.

More specifically, the visual acuity of little tuna, *Euthynnus yaito*, and skipjack is presently being measured. Such data provide information on the ability of these tuna to see an object of a certain size at various light intensities and distances underwater. In the sound studies the range of frequencies tuna can perceive and the minimum intensity that can be perceived at each frequency are being described.

Behaviour research both at sea and in shoreside tanks is concentrated upon feeding behaviour, social behaviour, and changes in behaviour throughout the day and night. Most sea work is directed at skipjack and yellowfin, *Thunnus albacares*, whereas most shore work is on skipjack, little tuna and bonito, *Sarda chiliensis*. The work on bonito is in co-operation with J. Prescott at Marineland of the Pacific in California.

At sea the stern underwater ports on the *Charles H. Gilbert* have provided an opportunity to observe feeding behaviour of tuna. Experiments were conducted in the waters of Hawaii and the Line Islands to determine the influence of different species of bait and artificial feeding stimuli on the feeding behaviour of skipjack (Yuen 1962)[7]. The fishing techniques of the Hawaiian sampan fleet were used: skipjack found by looking for bird flocks, were attracted to the vessel by chumming live bait into the sea, and were then caught on pole-and-line. Measurements were made of changes in catch rate and in the feeding rate (number of feeding attacks per fish per minute), which resulted from changing from live to dead bait, from one species of bait to another, or from turning off and on a water spray over the surface of the water. Catch rate increased when water sprays were turned on and decreased when they were turned off, when any one of six different species of chum was used. Both catch rate and feeding rate increased when living bait was chummed and decreased when dead bait was chummed. Catch rate is higher with the live bait because movement is one of the stimuli inducing feeding behaviour of skipjack, and because dead bait tends to drift away behind the vessel and take the skipjack away with it. Experiments using different species of bait are still in progress.

While being fished by the pole-and-line techniques, surface schools of skipjack characteristically dive or sound, returning to the surface seconds or as long as 28 min later (Strasburg 1961)[5]. Zero to eight dives were observed per school in Hawaiian waters and the frequency of diving was found to be associated with the occurrence of a lizard-fish, *Synodus variegatus*, and a squirrelfish, *Holocentrus lacteoguttatus*, in the stomach contents of the skipjack. It was hypothesised that these two species were more attractive than the live bait used by the fishermen and that the skipjack dived in pursuit of them.

Tuna schools are usually composed of fish of the same species and approximate size. Occasionally, pole-and-line or purse seine tuna boats catch both skipjack and yellowfin in a single fishing operation. Observations from the stern chamber of the *Charles H. Gilbert* have made it possible to study the structure of the school or schools from which such mixed catches are made (Yuen in 1963)[8]. When underwater movie sequences of such schools were analysed, it was obvious that each species tended to school with its own kind even though fish of the other species were near. A higher frequency of groups of a single species was observed than would have been expected if the fish schooled indiscriminately with the other species.

The floating observation raft is being used to discover the ecological significance of floating logs or flotsam to pelagic fishes. The reason that large numbers of dolphin fish and occasionally yellowfin and skipjack are found in the immediate vicinity of floating objects has been a debated question among fishermen for years. This study should provide some insight into the problem.

The three underwater viewing ports in the bow of the *Charles H. Gilbert* have been used to observe tuna, porpoise, flying fishes, and large plankton organisms. Most small fish dart rapidly away from the moving ship, but tuna and porpoise swim within view of the bow windows for prolonged periods of time. The bow viewing ports made it possible to observe in detail the behaviour of porpoise when riding the bow wave (Yuen 1961).

Very loose schools of skipjack have been observed in the central Pacific, with 7 to 18 yards between fish. These schools, 3 to 6 ft beneath the surface, were only one fish deep. During periods of observation when small numbers of natural prey were sighted by the skipjack, a vertical barred colour pattern appeared on the skipjack, and two or three of the fish nearest the prey organisms converged on them and fed. We have not yet succeeded in observing tuna in a feeding frenzy on natural prey concentrations, although we have attempted to do so by

heading the ship through areas marked by the surface splashes of feeding fish. Although the tuna were sighted by the underwater observer, they dived immediately and were not visible for prolonged periods.

Observations from the bow chamber on large plankton organisms in daylight and, by their luminescence, at night were interesting but difficult to record in numerical terms. It is hoped that the bow chamber can be used to estimate the abundance of surface fishes, but perhaps its greatest value will continue to be as a tool for making observations on marine mammals and fishes as the ship is actually moving with and within surface schools.

Direct observations at sea can be made on tuna that are either attracted near the observer by food stimuli, floating objects, or some other attractant, or that can be successfully followed at distances within 100 ft. This limits the spectrum of behaviour which can be observed at sea to feeding and schooling. In the shoreside tanks other aspects of behaviour can be examined, and feeding and schooling behaviour can be given closer scrutiny.

On shore the detailed patterns of tuna behaviour are first described. Whenever possible the function of the behaviour is determined. If the function is not obvious, experiments are devised to define the utility of the behaviour to the tuna. The functions of most of the observed patterns of behaviour have not yet been recognised. At present certain mouth movements, believed to be important in olfaction and food searching behaviour, are being investigated. The possibility of an olfactory function to the tuna's mouth movements was suggested by an anatomical study of the olfactory capsule of skipjack by Gooding (in 1963)[1]. An accessory sac of the olfactory capsule is compressed when the mouth is closing and inflated while the mouth is opening. This pumping seems to suck water into the naris and over the olfactory sense organ with each opening of the mouth.

Another interesting behaviour of tuna is the change from the typical striped coloration to a vertically barred coloration in skipjack (Nakamura 1962)[3]. This change results when a food stimulus is presented to a skipjack that has not eaten recently. A skipjack that has just eaten its fill does not take on the vertical pattern. The significance of this colour change is not yet known.

In addition to describing behaviour patterns and attempting to determine their function, the changes in behaviour, especially feeding motivation, occurring throughout the day are also being studied. The time of day when a tuna contacts prey and the amount of prey contacted can be expected to greatly influence the response of tuna to food stimuli during successive hours. For example, if skipjack are fed to excess all day long, they eat over half the food they will take during the day in the first three hours of daylight (Nakamura 1962)[3]. Presently, the variations in response to food are being associated with the previous prey-contact history of a tuna.

The present state of knowledge on tuna behaviour was recently summarised by Magnuson (in 1963)[2]. The inability to observe tuna behaviour directly at sea prior to 1958 greatly restricted the accumulation of knowledge. Now the tuna, still evasive and difficult to work with, is subject to the close scrutiny of the ethologist and comparative psychologist both in the field and in the laboratory. The understanding that these studies are providing should give man an additional advantage over the tuna in future exploitation.

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25. A Method of Measuring Visual Acuity of Scombrids

Development of techniques for capturing tunas and maintaining them in captivity has progressed sufficiently to allow subjection of these pelagic scombrids to experimental procedures. Experiments designed to measure the visual acuity of tunas have been developed recently at the U. S. Bureau of Commercial Fisheries Biological Laboratory in Honolulu.

The method involves training a fish to respond in a desired manner when a visual stimulus is presented. The visual stimulus is an image of either vertical or horizontal stripes which is projected onto an opal glass plate placed against a window of the tank. When the stripes are vertical, the fish is trained to swim down the tank to a food-drop area where it is rewarded. When the stripes are horizontal, the fish is trained to turn before it reaches the food-drop area and return to the far end of the tank. If it fails to turn around when horizontal stripes are presented, the fish receives an electric shock. The image is projected onto the opal glass plate when the fish is at the far end of the tank. The projector is turned off when the fish reaches a marked distance from the window. Filters are used to reduce the illumination of the striped image until the fish is no longer able to discriminate between vertical and horizontal stripes.

Visual angles are computed from measurements of the width of the stripes and of the distance between the fish's eyes and the striped image. Visual acuity is calculated by taking the reciprocal of the visual angle and is then plotted against the logarithm of the luminance of the image.

The experimental tank is enclosed in a Quonset hut so that lighting can be controlled. The observer, conducting the experiment from a booth so that he cannot be seen by the fish, uses remote control buttons to operate the projector, slide changer, and electric shocker. Food is dropped from a feeding tube attached to the booth.

Preliminary analysis of the data indicates a greater visual acuity for aku, *Katsuwonus pelamis*, than for kawakawa, *Euthynnus yaito*, at higher luminances. At lower luminances, the visual acuities of the two species of tunas are similar.

EUGENE L. NAKAMURA
U. S. Bureau of Commercial Fisheries

1964. /Abstract/ Proceedings of the Hawaiian Academy of Science. 39th Annual Meeting, 1963-1964, p. 26-27.

Separate from

SEA-WATER SYSTEMS FOR EXPERIMENTAL AQUARIUMS

A Collection of Papers

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
BUREAU OF SPORT FISHERIES AND WILDLIFE
RESEARCH REPORT 63

SALT WELL WATER FACILITIES AT THE BUREAU OF COMMERCIAL FISHERIES BIOLOGICAL LABORATORY, HONOLULU

By Eugene L. Nakamura, *Fishery Biologist*

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Abstract.—A salt well water system was developed in Honolulu to maintain skipjack tuna (*Katsuwonus pelamis*) in captivity. Problems encountered with the system included accumulation of rust from the cast-iron casing in the well, inability of the well to provide sufficient water for additional fish pools, inaccessibility of the aeration trays for cleaning, necessity of frequent cleanings of the fish pool due to algal growth, and inability to observe the fish closely because of wind ripples. These problems were remedied by drilling a larger well with an asbestos-cement casing, by building a new aerator with trays spaced farther apart and easily accessible, and by enclosing the new pool in a building.

A salt-water system was developed at the U.S. Bureau of Commercial Fisheries Laboratory's dock site in Honolulu in 1958 to maintain skipjack (*Katsuwonus pelamis*), a pelagic tuna, in captivity. Salt water from a well was used because of its freedom from sediments, pollution, dilution by rains, and fouling organisms (barnacles, mollusks, annelids, etc.). The system comprised a well, a pump, an aerator, a sump on which the aerator rested, and a fish pool (fig. 1). Polyvinyl-chloride pipes were used. The well, properties of the water, and the development of a suitable aerating device have been described in detail by Strasburg [preceding article in this collection]. While skipjack were being kept in the pool (Nakamura, 1960), certain shortcomings of this original system became apparent. These problems and their remedies are described in this report.

The casing of the well was a 3½-inch cast-iron pipe. Rust from this casing was deposited within the plastic pipes and on the perforated trays of the aerator. A layer of rust up to a millimeter thick lined the pipes after 18 months of use. Although rust was believed not to be harmful to the fish, it was undesirable because it reduced the bores of the pipes and the perforations in the trays and indicated deterioration of the well casing.

The limitations of the well's capacity became apparent when over 100 gallons per minute were pumped, for the water level in the well then dropped below the foot valve, which was 6 feet below the surface. This inadequate flow precluded the installation of additional fish pools.

It thus became apparent that a new well was required with a noncorrosive and nontoxic casing and of a capacity which should accommodate planned expansion.

The aerator was originally constructed so that the trays could be removed for cleaning. After about a year and a half of intermittent use, however, warping of the trays and swelling of the wood separating the trays made removal impos-

FIGURE 1.—Skipjack-holding pool, 23 feet in diameter and 4 feet deep. Behind the pool on the lef is the aerator resting on the sump, and on the right is the pumphouse. The well, which canno be seen, is between the pool and pumphouse.

sible. Since the trays were set 2 inches apart, the area between them was inaccessible for cleaning. Cleaning was desirable only because of the deposition of rust and not because of algal growth, which was inhibited by the enclosed situation of the trays within the aerator.

The aerator efficiently oxygenated the water (over 95 percent saturation), but did not adequately rid the water of carbon dioxide components. Excess carbon dioxide in the water caused the pH to be lower than that of normal sea water. The pH was 7.4–7.6 as compared with 8.1–8.3 in the open ocean (Sverdrup, Johnson, and Fleming, 1942). By rerouting the water through the aerator several times, the pH could be raised to 8.1 in 40 minutes, bu this recycling was not practical.

In order to remedy these undesirabl features of the aerator, plans for a replace ment were made. The trays were to b spaced to permit cleaning. Better ventila tion throughout the aerator was to be pro vided. Smaller but more numerous per forations were to be made in the trays s that the elimination of excess carbon diox ide would be improved.

The necessity of enclosing the pool in building became apparent for two reason First, the entrance of direct sunlight int the pool could be controlled to reduce o eliminate algae. In the outdoor pool, a gae grew rapidly, and frequent scrubbing

were required. Also, strands of a diatom (*Melosira* sp.) which broke off from the sides of the pool caused the water to become turbid. Second, the wind over the pool could also be reduced or eliminated. Wind ripples prevented clear observations through the water surface of the outdoor pool.

In August 1961 a new system was set into operation (fig. 2). The well is 73

FIGURE 2.—Present salt-water system. The pumps and well are housed in the building at the right. The aerator, in the center, is resting atop the concrete sump. The fish pool is housed in the quonset hut on the left.

feet deep, cased with a 12-inch asbestos-cement pipe down to 42 feet. The depth of the well was determined by the depth at which 1,000 gallons of water per minute could be provided. The depth of the casing was determined by the depth at which hard coral rock was reached. Water is presently being pumped at 82 gallons per minute, but the well is capable of providing water at 1,000 gallons per minute with a drawdown of 6 inches. A centrifugal pump with a cast-iron housing and a steel impeller is being used because this type of pump happened to be readily available. Thus far, its performance has been satisfactory.

The aerator is 6 feet wide, 7 feet 9 inches long, and 10 feet high at its apex. All four sides have louvers. The two ends are hinged so that they may be opened for cleaning. It houses 16 aeration trays spaced 6 inches apart. The trays are made

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of laminated plastic, measure 1/10 by 72 by 51 inches, and are perforated by 1/8-inch holes spaced 1 inch apart. Water sprays onto the top tray from 1/8-inch holes in the sides of the 2-inch inlet pipe.

The concrete fish pool is enclosed in a quonset hut. Water flows by gravity from the sump into the pool.

This new system appears to be satisfactory. Rust is no longer a problem. The pH has been raised to 7.8–8.0. The trays are easily accessible by opening the ends of the aerator. There is practically no algal growth in the pool, and the observatio through the water surface is excellent.

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OBSERVATIONS ON DOLPHINS (*CORYPHAENA* SPP.) IN THE CENTRAL PACIFIC OCEAN. — This note presents some observations made in the central Pacific Ocean on the common dolphin, *Coryphaena hippurus* Linnaeus, and the pompano dolphin, *Coryphaena equiselis* Linnaeus.

The observations were made during a study of the association of fishes with the transitional waters between the North Pacific Central (NPC) and the North Pacific Equatorial (NPE) water types. These transitional waters are called the California Current Extension (CCE). A recent discussion of these water types is given by Seckel (1962, *U. S. Fish Wildl. Serv., Fish. Bull.* 193). The sampling plan called for making 3 longline sets south of the transition zone in the North Pacific Equatorial water type (NPE), 3 in the North Pacific Central water type (NPC), and 3 in the transition zone. This pattern, traversing the CCE, was to be replicated 3 times, giving a total of 27 longline stations; unfortunately, owing to rough seas, only 6 stations could be occupied in NPC, so in all, 24 stations were fished. A preliminary report of the results of this fishing has been published (1963, *Comm. Fish. Rev.* 25(5):25–26).

The presence of dolphins at longline stations was noted either by observing them just below the surface during daily periods of 4–5 hr of continuous observation, or by catching them on the longline or on pole and line. In addition to the well-known morphological differences between the species, freshly caught adult *C. hippurus* and *C. equiselis* also exhibited striking color differences. Although *C. hippurus* underwent its usual striking color changes, a yellow suffusion remained evident on the head, lower lateral portions of the body, and lower lobe of the caudal fin, whereas *C. equiselis* has very little yellow coloration and, in general, is a uniform steely blue. While observed in the water, *C. equiselis* was distinguished easily from *C. hippurus* by its deeper body and its lack of what appeared in *C. hippurus* as a yellow caudal fin. This color difference was verified repeatedly by the capture of observed fish on hook and line.

Observations of the dolphins were made from the underwater viewing chamber of the research vessel CHARLES H. GILBERT, and on one occasion a banded color pattern was seen on a presumably adult *C. equiselis* by one of our field party (Gary H. Miller). This pattern, probably an ephemeral response to feeding, has been noted in several species and has been described in *C. hippurus* by several authors (Gibbs and Collette 1959, *Bull. Mar. Sci. Gulf Carib.* 9(2): 122; Strasburg and Marr 1961, *Copeia* 1961 (2):226–228).

Common dolphins were taken or observed at all but 2 stations, both in the CCE; at these 2 stations *C. equiselis* were taken. Pompano dolphins were taken or observed at 3 of the 6 NPC stations and at 7 of the 9 CCE stations. There was no evidence of the presence of pompano dolphins at any of the 9 stations fished in the NPE. Although the numbers of *C. equiselis* captured or observed were not large, the replicated nature of the observations suggests that it occurred only in the NPC and CCE water types. The observations further suggest that the pompano dolphin may be more abundant in the CCE than in the NPC. These observations do not rule out the possibility that *C. equiselis* may have been present in the NPE but could not be observed or caught by our methods. Whether the stratified distribution of *C. equiselis* is due to variables associated with latitude or to possible ecotonal influences of the boundary requires further study.

Meristic counts of anal rays (ray = spine or soft ray), dorsal rays, lateral-line scales, and gill rakers were made according to Hubbs and Lagler (1958, Fishes of the Great Lakes Region, *Cranbrook Inst. Sci. Bull.* 26) and are presented in Table 1. These data permit several contrasts with those reported by other authors. Counts of dorsal rays, anal rays, and gill-raker elements of *C. equiselis* of the Philippine area by Herre and Herald (1951, *Philippine J. Sci.* 79(3):327) are modally the same as our central Pacific data. Uchida (1935, *Bull. Jap. Soc. Sci. Fish.* 4(4):226) gave meristic data on several *C. equiselis* from Japan which are insufficient for comparison.

Gibbs and Collette (*op. cit.*:126–127) gave meristic counts on western Atlantic specimens of *C. hippurus* and *C. equiselis*, the latter mostly young and juveniles. Their counts will be compared with counts from

TABLE 1. FREQUENCY DISTRIBUTION OF DORSAL RAYS, ANAL RAYS, GILL RAKERS ON LOWER LIMB OF FIRST ARCH, AND LATERAL-LINE SCALES BY FIVE SCALE CLASSES FOR *Coryphaena equiselis* AND *Coryphaena hippurus* TAKEN IN THE CENTRAL PACIFIC OCEAN, JANUARY AND FEBRUARY 1963.

Species	Dorsal rays													
	49	50	51	52	53	54	55	56	57	58	59	60	61	62
C. equiselis	1	–	9	11	13	9	8	1	–	1	–	–	–	–
C. hippurus	–	–	–	–	–	3	5	11	18	12	15	10	7	1

	Anal rays							
	22	23	24	25	26	27	28	29
C. equiselis	2	–	10	21	16	3	1	–
C. hippurus	–	–	3	14	27	23	13	2

	Gill rakers				
	7	8	9	10	11
C. equiselis	–	1	7	34	11
C. hippurus	3	32	42	3	–

	Lateral-line scales																												
	161–165	166–170	171–175	176–180	181–185	186–190	191–195	196–200	201–205	206–210	211–215	216–220	221–225	226–230	231–235	236–240	241–245	246–250	251–255	256–260	261–265	266–270	271–275	276–280	281–285	286–290	291–295	296–300
C. equiselis	2	4	6	14	7	8	9	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
C. hippurus	–	–	–	–	–	–	–	–	–	–	1	1	–	–	5	8	4	8	5	14	7	5	10	5	3	4	–	1

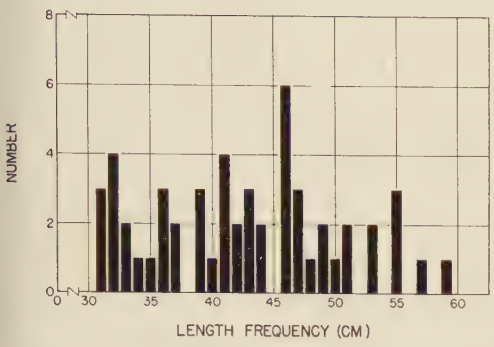

Fig. 1. Length–frequency distribution (FL) of 53 *C. equiselis* taken in central Pacific, January–February 1963.

our specimens. Dorsal rays of the western Atlantic and central Pacific samples of *C. equiselis* were modally the same. The modal number of anal rays for the Pacific specimens is one less than for the western Atlantic specimens. In central Pacific specimens the modal number of gill rakers is one greater than for the western Atlantic data. Differences in gill raker counts between central Pacific specimens and the western Atlantic data would be accentuated if the number of gill rakers were reduced with age, since the central Pacific counts were made only on adult fish. It also appears that the central Pacific samples of *C. equiselis* have fewer lateral-line scales than the western Atlantic specimens.

In *C. hippurus*, dorsal rays for the Pacific specimens appear to be fewer than for the western Atlantic data. Anal rays for the Pacific specimens are also modally 1 fewer than for the western Atlantic specimens. The modal number of gill rakers is 1 greater for the central Pacific than for the Atlantic samples. The high variability in counts of lateral-line scales makes comparisons difficult.

The size range of *C. equiselis* has not been reported except that they are generally smaller than *C. hippurus*. Uchida (*op. cit.*:224), in his English synopsis, reported that "the ordinary size of the fish landed is ca. 60 cm in length and 800~1,000 g. in weight." He also stated that *C. equiselis* may attain a weight of 2,500 g. Jordan (1907, Fishes. Henry Holt, N. Y., p. 502) noted that "*Coryphaena equiselis* rarely exceeds 2-1/2 feet." The fork lengths of our specimens of *C. equiselis* (Fig. 1) range between 308 and 587 mm.

Adult *C. hippurus* usually are thought to be piscivorous, feeding particularly on exocoetids (see, however, Gibbs and Collette, *op. cit.*:145–149). Stomach contents of 91 *C. hippurus* were examined. The results confirm that the common dolphin is piscivorous and takes exocoetids. Flying fish not only were the most numerous organisms in the stomach, but they also comprised a large portion of the total volume of stomach contents. Other important food items were gempylids and penaeid shrimps.

Nothing has been reported previously of the food habits of *C. equiselis*. The stomach contents of 53 individuals were examined. It should be noted that 39 of the 53 fish examined were from the same relatively large school, and consequently their stomach contents may not be representative. Bramids were the most common item in the stomachs of the pompano dolphin. In contrast to the common dolphin, exocoetids were not a common item in the diet of this species.

It has been surmised that feeding in *C. hippurus* is inhibited at night (Gibbs and Collette, *op. cit.*:149). On several occasions *C. hippurus* was observed chasing flying fish at night-light stations, and often this species was caught on hook and line from large schools that swam around the vessel as it drifted at night. On some occasions night-feeding by *C. hippurus* was observed when the water was brightly illuminated, but on other occasions there was evidence of feeding when the only source of artificial illumination was the dim running lights of the vessel. Stomachs of *C. hippurus* caught at night were examined. Several contained large, presumably freshly ingested myctophids. It seems probable that dolphin feed actively on bright moonlit nights. This supplies a speculative example of a mechanism by which elements of bathypelagic fauna contribute to the food web of epipelagic forms.

The observations reported in this note were made on the "Boundary I" cruise of the Charles H. Gilbert, research vessel of the Bureau of Commercial Fisheries Biological Laboratory at Honolulu. I wish to thank Mr. Gary H. Miller and Captain William Tanaka for their assistance in collecting specimens. Thanks are also due Frederick H. Berry for his comments. — Brian J. Rothschild, *Bureau of Commercial Fisheries, Biological Laboratory, Honolulu, Hawaii.*

21. Skipjack Tuna Oceanography

The broad concepts of fisheries oceanography are discussed in the context of studies on the skipjack tuna (*Katsuwonus pelamis*). Fisheries oceanography relates the study of fisheries with features of the oceanic environment.

In essence, fisheries science is an investigation of the harvest or yield of an exploited species. An attempt is made to maximize catch while minimizing the cost of fishing on a sustained basis. In order to regulate maximized catches and minimized costs, the components of yield must be investigated. By some models these components are recruitment, growth, natural mortality, and fishing mortality. An additional factor, availability, is of utmost importance in considering yields of tropical tunas.

Fisheries oceanography attempts to relate the components of yield with features of the oceanic environment. Some of these features are currents, winds, temperature, salinity, and productivity.

Our studies of the skipjack tuna are at a stage where we are defining our units of study. These units are groups of skipjack which differ from one another in life history attributes. For example skipjack spawn mostly in the northern winter in Marquesan waters, but in Hawaiian waters these fish spawn mostly in the northern summer. Some of these groups may be genetically distinct and are called subpopulations.

In order to study these units we have developed a model which for the first time formulates a working hypothesis to evaluate the origin and movements of exploited groups of skipjack in the eastern and central Pacific Ocean.

The principal features of this model follow:

1. Skipjack exploited in the eastern Pacific fishery consist of large numbers of fish which originate in the equatorial central Pacific.
2. The exit of skipjack from the area of the eastern Pacific fishery is associated with a spawning movement toward the central Pacific.
3. Skipjack taken in the Hawaii fishery include fish of both Hawaiian and equatorial origins.

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A MORPHOMETRIC STUDY OF YELLOWFIN TUNA *THUNNUS ALBACARES* (BONNATERRE)

By William F. Royce, *Director*
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ABSTRACT

orphometric measurements were compared for 0 yellowfin tuna from 28 locations in the Pacific an; from off Angola, Africa, in the Atlantic Ocean; from off Somaliland, Africa, in the Indian Ocean. measurements used were head length; pectoral fin gth; heights of second dorsal and anal fins; distances n snout to insertion of first dorsal fin, to second al fin, anal fin, and ventral fin; distance from in- ion of ventral to anterior edge of vent; and greatest y depth. Each measurement was related to fork gth by regression analysis, and each relationship was sidered a character. Curvilinear regression due to metric growth was controlled by transforming some a to logarithms and by separating all samples into ll, medium, and large size groups (less than 80, 20, and greater than 120 cm. fork lengths). Mean racter sizes were determined for each sample at gths of 65, 100, and 140 cm.

comparison of mean character sizes revealed a cline nost characters from samples taken along the Pacific ator between the vicinity of Costa Rica and the oline Islands. Yellowfin from the eastern Pacific e larger heads and greater distances from snout to rtion of first dorsal, second dorsal, ventral, and anal fins; a greater distance from insertion of ventral insertion of anal fin; and a greater body depth. other hand, they have shorter pectoral fins and shorter anal and second dorsal fins. The sample the more temperate parts of the Pacific and fr the coasts of Africa differed little from some part cline.

A multiple character comparison of overlap samples from near the Pacific Equator showed les 50-percent overlap between samples separated b miles, less than 25-percent overlap between sa separated by 3,000 miles, and less than 6-percen lap between samples separated by 6,000 miles possibility of long intermigrations among the eq ial stocks seems remote.

The full variation in length of the pectoral f heights of second dorsal and anal fins, which authors have used to separate the species of yel occurs within the cline along the Pacific Equator. occurrence, plus the continuous circumtropica seas distribution of the yellowfin, indicates a worldwide species. The appropriate name is *Th albacares* (Bonnaterre) 1788.

. problem of immediate concern to us in investi- ion of the tuna fisheries of the Pacific is to ermine the degree of intermingling of the tuna ulations. Intermingling matters because tunas being sought in different parts of the ocean by ermen who are asking whether the catch by one ion in one area is affecting the population of as and catch by another nation in another area. other words, do these tunas migrate thousands niles, as do some of our migratory birds, or are y relatively localized, hatching, maturing, and dying within an area of a few hundred mile closely related matter of secondary concern distinguish the species and subspecies of each of tuna in the oceans of the world.

Among the tuna fisheries of the Pacific, the the yellowfin (*Thunnus albacares*) [1] are the

Note.—Approved for publication June 3, 1963.

[1] The Pacific yellowfin tuna has been named *Neothunnus ma* (Temminck and Schlegel) by recent authors. I consider the yellow a single worldwide species, which I choose to call *Thunnus albacares* 428).

nt. The yellowfin is a major fishery re-
rom California to Chile and from Japan to
ia, especially near the Caroline Islands.
fisheries also exist off Hawaii, Australia,
ny of the islands of the central Pacific. In
, exploration by the Bureau of Commercial
s Pacific Oceanic Fishery Investigations
[2] in the central Pacific revealed major
rations of yellowfin along the Equator from
le 110° W. to 180°. These stocks were
epeatedly by research vessels and sub-
commercial vessels between 1950 and 1955.
thods and results have been summarized
e (1954) and detailed by Murphy and
a (1953a, 1953b, and 1955) and Shomura
rphy (1955). Since 1955 these populations
een fished with increasing intensity by
e commercial concerns.

pproach to the general problem of relations
Pacific tuna stocks has been through
metric studies. Workers have included
r (1948), who described the morphometric
eristics and relative growth of yellowfin off
America; Godsil (1948), who made a
ary population study of yellowfin and
, *Germo alalunga* (Bonnaterre); Schaefer
lford (1950), who compared yellowfin from
ola, Africa, and the Pacific coast of Central
; Schaefer (1952), who compared yellowfin
e Hawaiian Islands with those from the
coast of Central America; Royce (1953),
npared numerous groups of Pacific yellow-
ruta (1954), who compared yellowfin from
ert Islands with those from Hawaii; and
(1955), who further compared yellowfin
m Central America and Hawaii with those
eastern Polynesia.

ifferent technique, which may provide
vidence of intermingling, has been applied
California Department of Fish and Game,
Fisheries Branch, and used subsequently
r groups. Yellowfin, albacore, and skip-
atsuwonus pelamis (Linnaeus), have been
with plastic tags, as reported by Wilson
and have already shown some remarkable
ns. One albacore released 18 miles south
Angeles, California, was recovered nearly
ater about 5,000 miles distant at latitude
N., longitude 149°40′ E., off the coast of

[2] Biological Laboratory of the Bureau of Commercial Fisheries, Hawaii.

Japan (Ganssle and Clemens, 1953) and two ot
albacore, tagged near Guadalupe Island, w
recovered about 6 months later in the vicinity
Midway Island (Blunt, 1954). Yellowfin
were tagged off the Line Islands from March 1
to February 1956 (Iversen and Yoshida, 19
Of the 1,056 that were released, 2 were recaptu
locally and 1 was recovered 800 miles east of
point of release after being at liberty 13 mon
But these tag returns are as yet too few to prov
good evidence of the extent of intermingling o
any different migratory behavior of the sev
species.

Much interest in these problems of intermingl
of tuna populations has been expressed at vari
meetings of the Indo-Pacific Fisheries Cou
and the collection of data has been a matte
major concern to its Tuna Subcommit
Through this organization the aid of numer
people in the Indo-Pacific area has been enlis
in the collection of data, which have been use
this report. This interest has also been expres
by some independent studies along the same li
in other countries, particularly in Japan
Tsuruta (1954) and in Australia where morp
metric studies are underway.

STATISTICAL COMPARISON OF MORPH
LOGICAL DATA

The following section is a summary of a gen
review of the problem involved in statist
comparisons of morphological data previou
made by Royce (1957).

In all morphometric studies of yellowfin t
the authors have used essentially the sa
methods. All have used measurements of b
parts, especially lengths and heights of the
and distances from the snout to insertion of
fins, as principal characters. All have u
regression analysis to relate part size to f
length and then have compared samples
covariance analysis. All have found much la
differences between samples than would be
pected from chance variations, and from s
differences there has been a tendency to concl
that the populations were distinct.

But this method of analysis is not wholly sa
factory. It provides a test of whether a differe
is significant, but this conclusion may be triv
because significant differences can be found co
monly between even the most closely rela

ural populations (Mayr, Linsley, and Usinger, 3: 151). It does not show how great the erences are in terms that can readily be com- ed. It does not provide evidence of clines or racter gradients, which are to be expected in a populations because of their continuous dis- ution and which are useful indicators of rela- s of the populations. Neither do the methods current use provide information on the key blem of the amount of intermingling.

Use of regression analysis to relate size of body ts to fork length does provide basic data ded for finding clines according to the method cribed by Hubbs and Hubbs (1953). The ression statistics provide the mean character estimated for a fixed length of fish; the asure of dispersion about the mean, which is standard deviation from regression; and the asure of reliability, which is the standard error the estimated mean. I showed that clines t among yellowfin tuna populations (Royce, 3), but I did not use the method of Hubbs and bbs nor employ sufficiently precise methods of ression analysis. In this paper I will use more ned methods of regression analysis and try to w fully the nature of the clines.

The problem of intermingling will be approached ough an extension of the concept of overlap, ch has been applied to comparison of natural ulations by many taxonomists. The methods current use have been summarized by Mayr, sley, and Usinger (1953: 142). They have icated overlap between populations by a fficient of difference (CD), which is computed ording to the formula—

$$CD=\frac{\bar{x}_1-\bar{x}_2}{s_1+s_2}$$

e overlap is the difference between means $\bar{x}_i$ ided by the sum of standard deviations s_i of two populations. I prefer to change this nula slightly to—

$$D=\frac{\bar{x}_1-\bar{x}_2}{s}$$

which s is the within-sample standard deviation nputed from the pooled variance, and D is the ance between the means in the standard sure of statistics, i.e., in units of the standard iation. It is obvious that $CD\simeq\frac{D}{2}$.

The concept of overlap of two frequenc tributions is shown graphically (1A an in figure 1. The mutual area (1B and 2

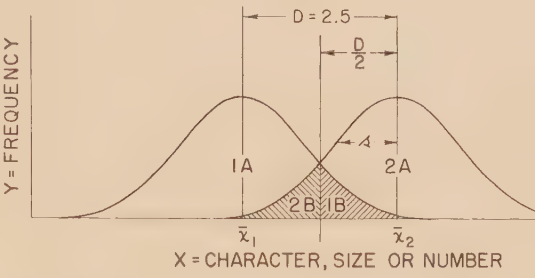


FIGURE 1.—Overlap of normal distributions. 1 2A indicate normal populations which overlap shaded areas 1B and 2B; s indicates one st deviation, $\bar{x}_1$ and $\bar{x}_2$ indicate means; D is the d between means in units of the standard deviatio

the two curves is shaded; one-half of the s area, or tail of one distribution, which I des as p, may be determined readily from a table probability integral, such as table 2 in P (1948). The table is entered with the va $\frac{D}{2}$. The value of p represents the proba of misclassifying the individuals on the of the character used. When the two are identical and the chances of making a choice are equal, p will range from 0.5 to esse zero when the two curves are widely sepa and for all practical purposes there is no ov However, the value p, while indicative of ov is not fully satisfactory because it approa maximum of 0.5 and because it must be cons properly as a probability of misclassifi rather than a measure of the mutual area frequency curves.

A more satisfactory measure of overla be obtained if one considers the area frequency curve and within it the proportio that might belong to another specified frequency I have designated this by $\Omega=200\ p$, exp as a percentage. It is a measure of o which will be 100 percent when the curve the same mean and will approach zero means become widely separated.

The particular usefulness of Ω is in the c that it is an estimate of the proportion sample with the characteristics of anoth the samples are representative of populati

716-687 O—64——10

ic time and place, it follows that Ω is that ion which might have come from another ion, and thus the value of the overlap es a maximum for the amount of intermin- The overlap Ω does not show that inter- g has occurred, and when large it merely hat a large amount of intermingling may curred. Whether intermingling did occur e determined by other means. When Ω , however, and we can establish that the ers used do not change during migration, then be able to establish that no significant ngling occurs.

most satisfactory measure of overlap is d from several characters simultaneously, requires a substantial extension of the ations. The measure in current use by axonomists has been applied merely to isons of single counted characters. I have (Royce, 1957) that it may be applied to single measured characters through ution of the regression statistics. The reater extension to multiple characters is on D as already defined. The use of D distance between populations has been ized for multiple characters by Mahalano- 36). In his generalization, each additional er adds to D only to the extent that it correlated with previously considered ers. Thus, all arbitrary combinations acters as ratios or indices are avoided. 947, 1952) pointed out that D satisfies ndamental postulates of distance: (1) the e between two groups is not less than zero; sum of distances from one group to two roups is not less than the distance between other groups (triangle law of distance). rther empirical requirement that the dis- ust not decrease when additional characters sidered is also satisfied.

AVAILABLE DATA

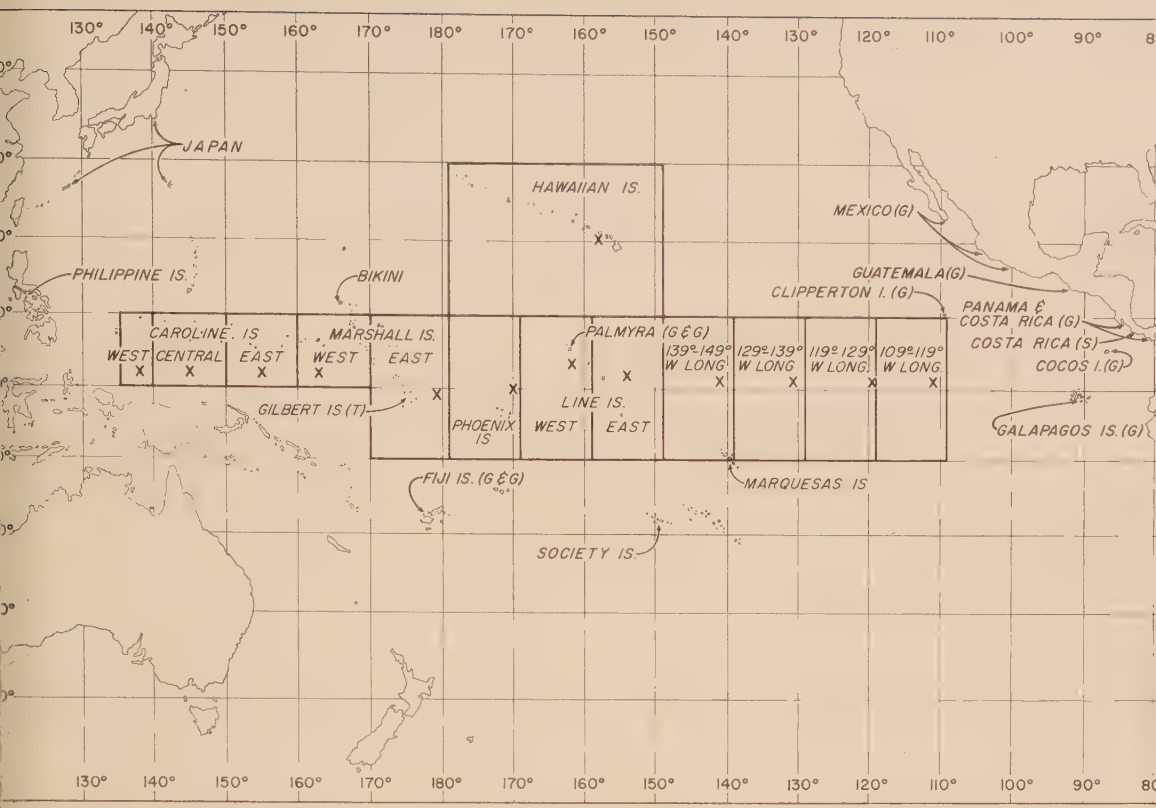
e were available for this study 28 samples owfin from the Pacific Ocean, 1 from the c Ocean off Angola, Africa, 1 from the Ocean off Somaliland in northeast Africa, of only 3 specimens from off Ceylon.[3] ta include the measurements of yellowfin from off the American coast published by Go (1948), whose 13 samples have been combi into 6; those from off Costa Rica by Schae (1948); from Angola by Schaefer and Walf (1950); from Fiji, Palmyra, and Hawaii by Go and Greenhood (1951); from Hawaii by Schae (1952); and those from the Gilbert Islands Tsuruta (1954). The original measurements most of the remaining samples were publis by Dung and Royce (1953). The remainde sample from the Pacific Equator near longit 110° W. and another from northeast Africa, listed in appendix tables 1 and 2.

The geographic distribution of Pacific sam is shown in figure 2. There is an excellent se from about 8,000 miles along the Pacific Equa between the American coast and the cen Caroline Islands. In addition, there are sam from the South Pacific off the Fiji and Soci Islands, and from the North Pacific off Philippines, Japan, Bikini Island, Hawaii, Mex and Guatemala. All major areas of the Pac where yellowfin are known to occur are inclu except the South American coast and the so west Pacific from Australia to the coast of A

It was necessary to omit four samples from Pacific. Those from the western Marshall, w ern Caroline, and Fiji Islands have not b further considered, because they contain less t 20 fish, the number I arbitrarily established the minimum. In another sample from t the Gilbert Islands, reported by Tsuruta (19 measurements of one specimen are question (No. 2 in his table 1), and I have been unabl verify the computations shown in his table Fairly large discrepancies occur in the regress statistics, apparently because enough digits w not carried during the computations. This sam was obtained on only 3 days from a limited a For these reasons I have not further considered

Certain basic statistics about the samples be needed repeatedly in the ensuing discuss and are presented here. The length distribu of all samples is shown in table 1. Pertinent d on how the samples finally used were colle are shown in table 2. The sums, sums of squa and sums of products for all characters of samples which have not been published are gi in appendix table 3. Included, also, are the me regression constants, and estimated chara sizes at certain lengths for all samples.

[3] mple was compared with the Pacific samples by Royce (1953) o be most like the Phoenix Islands sample. It will not be further here.



IGURE 2.—Geographic distribution of Pacific samples of yellowfin tuna. (X indicates approximate center of tribution of fish comprising each sample from Hawaii and the equatorial area. (G) indicates Godsil, 1 (G & G) Godsil and Greenhood, 1951; (S) Schaefer, 1952; (T) Tsuruta, 1954.)

RPHOLOGICAL CHARACTERS USED

he morphological characters I have used in study were selected through precedent and erience. The precedent was established by eral workers who attempted thorough morpho-ric studies. None of the recent workers haefer, 1948; Godsil, 1948; or Schaefer and lford, 1950) explained how they selected their racters, but undoubtedly they were guided by vious research reported in the literature in ch yellowfin tuna had been differentiated ely on the basis of fin length. Godsil (1948) ned 16 measurements but presented data on 6: fork length; head length; and distances n the snout to insertion of first dorsal, second sal, anal, and ventral fins. He states that he stigated counts but discarded them because were unsatisfactory. Schaefer (1948) used of these measurements (he did not measure t to insertion of ventral fin). He added the test body depth; length or height of the pec-l, second dorsal, and anal fins; longest dorsal finlet and dorsal ray; distance from pecto insertion to insertion of first dorsal fin; len the base of first dorsal fin; diameter of iri length of maxillary. In addition, he ob four counts: number of dorsal fin rays (inc spines if any), dorsal finlets, anal finlets gill rakers.

Schaefer and Walford (1950), for part specimens measured off Angola, Africa, use same measurements as Schaefer (1948), but spread of caudal fin, length of first dorsal least depth of caudal peduncle, greatest wi caudal peduncle at keels, and snout to ins of ventral fins. They also obtained the sam counts and recorded the sex of some of the Subsequently, this list of measurements markedly reduced by Schaefer (while he directing the morphometric program at PO fork length; head length; snout to inserti first dorsal, second dorsal, anal, and ventra length or height of pectoral, second dorsa anal fins; greatest body depth; and diameter

TABLE 1.—*Number of tuna measured, by size interval and place of collection*

Area	Number of fish in fork length (cm.) interval of—														
	30–39.9	40–49.9	50–59.9	60–69.9	70–79.9	80–89.9	90–99.9	100–109.9	110–119.9	120–129.9	130–139.9	140–149.9	150–159.9	160–169.9	170–179.9
Mexico [1]			52	143	155	8	3								
Guatemala [1]			49	54	16	1									
Panama and Costa Rica [1]		1	129	283	282	36	42	43	48	20	3				
Costa Rica [2]			2	7	3	6	11	6	6	2		2	1		
Cocos Island [1]		6	8	36	128	80	28	2		4	10	5	4		
Galapagos Island [1]			97	14	9	65	9								
Clipperton Island [1]			1	21	7	4	2	1	2						
109°–119° W					1	2		1	2	3		7	5	6	
119°–129° W										3	10	16	14	4	
129°–139° W				1	1		1			5	5	12	10	11	
139°–149° W										4	25	29	33	20	2
East Line Islands				1	4	4	8	16	5	12	35	48	52	10	
West Line Islands		1	5	16	22	28	22	19	17	11	21	18	7	1	
Palmyra Island [3]			1	10	24	18	27	10	2	1		1			
Phoenix Islands			4	19	14	16	19	9	15	15	21	7	2	1	
East Marshall Islands									2	6	16	16			
Gilbert Islands [5]									2	3	13	14	1		
West Marshall Islands	2	2	7	1									4	2	
Bikini Island			21	6	4	5	4	3	1						
East Caroline Islands		1	18	23	18	19	16	6	14	12	21	9	13	1	
Central Caroline Islands		1	6	11	19	21	21	33	27	33	24	13	2		
West Caroline Islands				2	1	1	3		2	7	1				
Philippines (SW. Panay)		1	58	121	62	47	19	9	6	15	11	5	2		
Japan	1	11	6	6	7	8	6	1							
Hawaii [2]		16	15	3	2	4	9	15	6	17	29	22	15	32	18
Hawaii [3]			42	5		11			1		7	11	1	1	
Society Islands		2	15	3	2	7	1					2			
Fiji Islands [3]			1	2		3	1	6							
Northeast Africa				5	12	30		1							
Angola, Africa [4]		1			11	11	1		9	8	9	6	2	2	
Total	3	43	537	793	804	435	253	181	167	181	261	243	168	91	20

[1] Godsil (1948). [2] Schaefer (1952). [3] Godsil and Greenhood (1951). [4] Schaefer and Walford (1950). [5] Tsuruta (1954).

iris. But another measurement was added—the distance from insertion of the ventral fins to the anterior edge of the vent.

This reduction was undertaken without conclusive evidence that the omitted characters were less satisfactory than those retained; but some reduction was clearly necessary in order to have a manageable number of characters, and we think that the selection was good. The characters retained are, in general, external measurements that differentiate several species of tuna closely related to the yellowfin. Of special importance are length of the pectoral fin, length of the anal and second dorsal fins, and the general body proportions, which are reflected by length of the head and distance to the insertions of several fins. It is reasonable to assume that if these characters have differentiated during evolution of these other tuna species, they may well be differentiating in the evolution of the yellowfin group.

Some characters were excluded because they were troublesome to measure or count. For example, the counting of dorsal and anal finlets is complicated occasionally by the apparent absence of a finlet in the midst of the series. Sometimes it is obvious that a finlet has been torn off, at other times it is uncertain whether there had been a finlet in the space. The diameter of the iris been omitted because of confusion among workers between measuring the diameter of iris and that of the eye. When plotted, t measurements seemed to fall into two groups we found that measurements had been take different ways. We also have not used the raker counts, even though we obtained consi able numbers of them, because of uncerta that our numerous field people were counting rakers in the same way. The difficulty is that rakers become progressively smaller on one sid the gill arch until covered by skin and, in any g examination such as must be made in the fiel is always necessary to decide whether certain rakers are big enough to be counted. In addit the number of gill rakers is not entirely i pendent of length of the fish. In one long se of counts made with great care in the laborat on yellowfin from a single area, we found a st tically significant association between numbe gill rakers and length of the fish.

Thus, the selection of characters has obvio been haphazard and I cannot claim to have s ted the best ones. I can say only that they the principal external characters which have se to differentiate the species of tunas and t

TABLE 2.—*Characteristics of yellowfin tuna morphometric samples*

[Size groups: S, < 80 cm., M, 80–120 cm., and L, > 120 cm.]

Area and size group	Number	Mean fork length (cm.)	Sampling effort				Numbers of fish by gear [1]			Remarks
			Years	Months	Days	Examiners	Long-line	Pole and line	Troll	
co: [2] S	361	68.46	2	2	5	1		361		(2)
emala: [2] S	120	62.26	1	1	2	1		120		
ma and Costa Rica: [2]	887	75.19	3	5	?	1		887		
Rica: [2] M	29	99.88	1	6	?	[4] 2		29		
s Island: [2]	311	82.16	2	2	<6	1		311		
pagos Island: [2] S	194	68.32	1	1	?	1		194		
erton Island: [2] S	38	73.89	1	1	3	1		38		
119° W.: L	21	149.82	1	1	5	[4] 2	21			
129° W.: L	47	146.72	1	4	12	4	46			
139° W.: L	47	144.67	1	3	15	5	45		2	From catches of POFI vessels.
149° W.: L	113	148.73	1	3	23	6	109		1	
Line Islands:										
	33	102.51	3	8	13	9	17		16	
	157	145.35	4	9	36	9	149		3	
Line Islands:										
	44	68.68	4	9	28	9	1	7	32	
	87	97.76	4	8	31	9	7	8	63	
	58	138.13	4	8	23	8	46	1	9	
yra Island: [5]	35	72.49	1	1	Ca.	1				All fishing done close to Palmyra, Fanning and Christmas Islands.
	57	94.38	1	1	12	1				
nix Islands:	37	67.67	3	5	16	5	1	9	27	
	59	98.23	2	6	24	7		16	42	From catches of POFI vessels.
	46	133.53	3	6	26	7	19	13	9	
Marshall Islands: L	40	136.34	1	1	8	3	32			
i Island: S	31	59.03	1	2	?	1			31	Measured by J. C. Marr.
Caroline Islands:	60	65.27	2	6	24	[4] 3	59	1		
	55	98.26	2	4	20	[4] 2	55			
	56	139.95	2	5	21	[4] 3	56			Obtained by POFI observers on Japanese mothership expeditions.
al Caroline Islands:	37	67.94	1	3	17	[4] 2	36	1		
	102	100.88	1	3	22	[4] 2	102			
	72	132.29	2	4	17	[4] 3	72			
pines:	242	65.19								Contributed by D. V. Villadolid, Philippine Bureau of Fisheries.
	81	90.74								
	33	132.99								
: S	31	57.73	1	2	7	1	1	28		Measured by POFI observers in Japan.
ii:	36	52.35	2	7	17	4		19	5	From POFI catches and Honolulu fish market.
	34	101.95	1	7	21	[4] 4	15	15	2	
	133	150.04	1	7	77	[4] 4	129	1		
ii: [5]	47	57.01	1			1				From near Johnston Island and near islands northwest of Kauai.
	20	142.96	1			1				From Honolulu market.
y Islands: S	22	57.30	1			4		22		From frozen fish landed in Honolulu.
east Africa: S	48	79.15	1	2	9	1				Courtesy of FAO, measured by A. Fraser-Brunner.
a, Africa: [6]	21	97.64	1	1	4	1				
	27	137.67	1	1	4	1				

A few specimens lacked record of gear used. [2] Statistics based on curvilinear regressions, Godsil (1948). Additional information from correspondence. [3] Schaefer (1952). [4] More than half of samples measured by one person. [5] Godsil and Greenhood (1951). [6] Schaefer and Walford (1950).

ear to be the most variable ones within the owfin group that can be measured with pre- on and consistency by different people.

METHODS OF MEASUREMENT

ur methods of measuring tuna follow the ifications given by Marr and Schaefer (1949). ink we have measured the fish exactly as they nded, but we slightly modified their definitions overcome some confusion existing among our surers. The most recent instructions given FI workers have been as follows:

The measurements described are all made in millimeters with calipers or dividers, depending on the size of the fish and the distance to be measured. All distances are straight lines. The tip of the fixed arm of the calipers (or one point of the dividers) is applied to the first point mentioned and the tip of the sliding arm of the calipers (or the other point of the dividers) is applied to the second point mentioned. Where a choice of sides is involved, all measurements and counts are made on the left side of the fish. Fin insertions are to

be determined while holding the fin approximately perpendicular to the contour of the fish.

Fork length.—(Total length of Marr, Schaefer, and Godsil.) The distance from the tip of the snout (most anterior point on upper jaw), with jaws closed, to the cartilaginous median part of the caudal fork (seating the sliding arm of the caliper firmly and thus depressing the small fleshy flap extending posteriorly).

Head length.—Distance from the tip of the snout to the most posterior point on the margin of the subopercle (depressing the fleshy flap extending posteriorly).

Snout to insertion of first dorsal fin.—The distance from the tip of the snout to the insertion of the first dorsal. The insertion of the first dorsal is the intersection of the anterior margin of the first dorsal spine, when the fin is held erect, with the contour of the back. This point is identical with the most anterior point of the first dorsal fin slot.

Snout to insertion of second dorsal fin.—The distance from the tip of the snout to insertion of the second dorsal. The insertion of the second dorsal is not so clearly defined as the insertion of the first dorsal, particularly on larger fish; but it is the intersection of the anterior margin of the second dorsal with the contour of the back when the fin is held erect. When the second dorsal is raised, the determined point should be marked with thumbnail or scalpel.

Snout to insertion of anal fin.—The distance from the tip of the snout to the insertion of the anal fin. The insertion of the anal fin is determined in the same manner as the insertion of the second dorsal.

Snout to insertion of ventral fin.—The distance from the tip of the snout to the insertion of the ventral. The insertion of the ventral is the intersection of the anterior margin of the ventral, when the fin is extended, with the contour of the body.

Insertion of ventral fins to anterior edge of vent.—The midline distance from the insertion of the ventrals to the anterior edge of the vent.

Greatest body depth.—The greatest distance between the dorsal and ventral contours perpendicular to the axis of the fish. The measurement is taken from the dorsal body contour to the ventral body contour, with the first dorsal fin depressed in its slot. It is oriented by reference to the dorsal spine, the insertion of which is a nearest to the upper end of the vertical. Do spines are counted posteriorly, the most ante spine being the first.

Length of pectoral fin.—The distance from anterior end of the fin slot to the most poste point, taken with the pectoral fin extended teriorly and opposed to the side.

Height (length) of second dorsal fin.—The tance from the insertion of the second dorsal to its distal end, with the fin in a normal posit Note that this fin is often extended in a filament, especially in large Neothunnus, and should be taken to notice if this extension is fra

Height (length) of anal fin.—The distance f the insertion of the anal fin to its distal end, the fin in a normal position. Remarks u height of second dorsal fin apply here.

Diameter of iris.—The greatest diameter m ured to the margin of the yellow iris and adjoining black tissue. This is generally n line parallel to the median line of the body.

Number of gill rakers.—The number of ante rakers on the most anterior gill arch on the side of the fish (some species also have poste rakers on this same arch). The counts of rakers on the two arms of the arch are kept se rate. For example, 10+20=30 gill rakers 10 on the upper arm and 20 on the lower. counts include all rakers that project above surrounding epithelium. We have encounte no difficulty in assigning rakers near the angl the arch to one arm or the other.

Sex.—Determined by inspection. Very im ture males and females may be difficult to tinguish. Ovaries, which are tubular, may o roll between the fingers, while testes, which solid, will turn over. The testes of ripening ripe males are enlarged, solid, white bodies, round in cross section. The ovaries of ripenin ripe females are enlarged, turgid, pink or yell orange bodies, round in cross section. Ova often be distinguishable with the naked eye. testes of spawned-out males are less tur tougher, and pinker than those not spawned, are difficult or impossible to distinguish f maturing testes in early stages. The ovarie spawned-out females are hollow, more or flabby, saclike tubes.

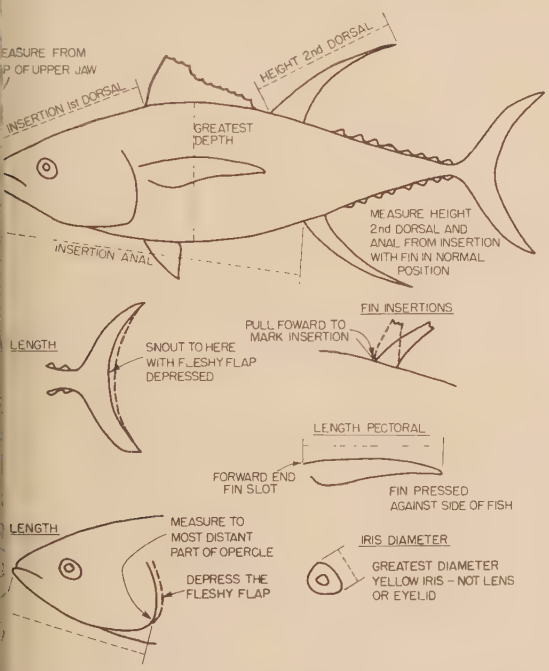
Weight.—Should be determined in pounds steelyards of proper range. Do not weigh

lyard having capacity greater than about three
es the weight. Be sure to subtract the weight
ny hooks used to hold the fish. Record weight
smallest unit on steelyard. Note if fish is
ghed in pieces.

IMPORTANT

heck steelyards before each cruise. Errors
t not exceed 1 percent.
heck calipers each time they are used. Errors
st not exceed 1 mm.
n addition to these instructions, diagrams were
vided on the back of each field sheet (fig. 3).
ll measurements of distances exceeding about
mm. have been obtained with sliding calipers.
s lower limit occurs because some of our calipers
not measure closer than that and hence the
rter distances have been measured with dividers
millimeter rule. All measurements are the
ual distance between two points and not the
ance parallel to the midline of the body and
ween perpendiculars as specified by LeGall
51) for body measurements of European tunas.
Our calipers have usually been of two sizes, 1 m.
2 m. They evolved through brass and alu-
num to standard wooden meter sticks.

DIAGRAMS SHOWING CERTAIN MORPHOMETRIC MEASUREMENTS OF TUNA


EASURE FROM
P OF UPPER JAW
INSERTION 1st DORSAL
HEIGHT 2nd DORSAL
GREATEST DEPTH
MEASURE HEIGHT 2nd DORSAL AND ANAL FROM INSERTION WITH FIN IN NORMAL POSITION
INSERTION ANAL
FIN INSERTIONS
PULL FOWARD TO MARK INSERTION
LENGTH
SNOUT TO HERE WITH FLESHY FLAP DEPRESSED
LENGTH PECTORAL
FORWARD END FIN SLOT
FIN PRESSED AGAINST SIDE OF FISH
LENGTH
MEASURE TO MOST DISTANT PART OF OPERCLE
DEPRESS THE FLESHY FLAP
IRIS DIAMETER
GREATEST DIAMETER YELLOW IRIS – NOT LENS OR EYELID
ALL MEASUREMENTS WITH CALIPERS OR DIVIDERS WHILE FISH IS LYING ON ITS RIGHT SIDE

RE 3.—Diagrams on the back of the field data sheet
owing certain morphometric measurements of tuna.

The 1-m. caliper consisted simply of a fixed jaw and a slider on a standard meter stick. If the meter sticks are selected with care to get straight ones, we find it easy to maintain the accuracy within 1 mm. by checking the caliper prior to each use. (We found this checking equally essential with the metal calipers because of the ease with which they can be bent.) For the 2-m. calipers we put two meter sticks end to end in a sheet aluminum channel. The channel was made slightly longer than the two meter sticks to permit a third meter stick with a movable jaw to be inserted when we were measuring large sharks or marlins more than 2 m. long.

Almost all of our measurements were obtained in the field and usually on shipboard. In equatorial areas on POFI vessels it was customary to measure up to about 10 tuna of all species during the course of a day's fishing. During longline fishing operations, which were usually carried out along a line of stations, this ensured that the sample included tunas from a wide-spread area. On the Japanese mothership expeditions in the Caroline Islands area, POFI observers measured fish on the deck of the mothership a few days after capture by catcher vessels.

The original measurements not obtained on POFI vessels came from a variety of sources. In the Honolulu area most measurements were from specimens received at the fresh fish market. The Japanese specimens were measured by members of the POFI reconnaissance team that visited Japanese markets in 1949. Specimens from the Society Islands were measured from the catch of the vessel *Hawaiian Tuna* when they were landed at the Honolulu market and after they had thawed.

METHODS OF COMPUTATION

As indicated in the general discussion on the comparison of morphometric data, I have not considered ratios or indexes but have used regression analysis entirely in order to control the effect of size of fish in our comparisons. I have used the regressions for yellowfin tuna proposed by Schaefer (1948), who stated that the original measurements provided a satisfactory straight-line relation with fork length in the case of head length, snout to insertion of first dorsal fin, snout to insertion of second dorsal fin, snout to insertion of anal fin,

and greatest body depth.[4] For the length of the pectoral fin he used the actual length of the fin with the logarithm of fork length, and for heights of the second dorsal and anal fins he used the logarithm of length of fin with the logarithm of fork length. For the other character, the distance from the insertion of the ventral fins to the anterior edge of the vent, which Schaefer (1948) did not use, no transformation is needed to obtain a reasonably straight line.

After accumulating several thousand sets of measurements for several species of tunas, we found that the labor of analysis was beyond our facilities and we turned to the International Business Machines Corporation for assistance. On most of our material, in which the original field data sheets had one fish per sheet, codes were added for species, locality, 10-cm.-length group, month, year, sex, and the examiner. Certain measurements were transformed to logarithms and the code and measurements were punched on cards. It was then possible to square, cross multiply, and tabulate automatically. A complete tabulation of sums, sums of squares, and sums of the products for regression analysis was obtained, arranged according to species, locality, and 10-cm.-length group. Subsequently, special tabulations of the material were made as needed.

After the data had been completely tabulated and totaled, scatter diagrams were made for each character on all specimens from each area to permit an immediate judgment of aberrant observations. If any data were obviously aberrant,[5] they were checked with the original field data, and, if plotted as recorded, they were assumed to be in error and were discarded. The regression line was then computed and plotted along with parallel lines plus and minus three standard deviations from regression. At this time, any remaining points more than three standard deviations from regression were assumed to be in error and were dropped. Then, final regression and the standard deviation from regression were computed. I have not tabulated the number of discarded observations, but I estimate it to be less than 2 percent of the total.

[4] An evaluation of the regression formulae will be found in the following section.

[5] This was usually more than about 15 percent (about four standard deviations) of the size of the character away from the general trend.

Discarding any data is questionable because c
rect but unusual observations may be discard
By my method, however, most of those drop
were far removed from the line. The rejec
values frequently were so located that one
pected that digits had been transposed or er
made in the decimeter digit. I believe that
if any correct observations were discarded. I
thermore, some culling is desirable for all dat
this kind which have been collected under diffi
field conditions where it is not practical to ch
original measurements.

Checks were made at all stages of computati
All IBM card punching was verified. All desk
culator operations that could not be independe
checked were repeated. Finally, the plots of
regression line and standard deviations from
gression provided a visual check which detec
any but trivial errors.

SELECTION OF REGRESSION EQUATIO

In the analysis of yellowfin tuna morphomet
two fundamental statistics, mean and varia
are required. Both must be unbiased estimate
corresponding population parameters. These
tistics are estimated from the best regression
mulae. If I apply straight line regressions to d
that are curvilinear, then my estimates of
means may diverge an unknown amount from
population parameter and the estimates of
iance will tend to be excessive. On the other ha
curvilinear regression techniques tremendo
increase already laborious calculations and
practical reasons should be avoided unless f
justified.

The two authors who have dealt with rela
growth of the yellowfin tuna are in fundame
disagreement on whether curvilinear regressio
needed for several characters. Schaefer (19
117) stated, "Over the range of sizes conside
all the characters measured, with the exceptio
the lengths of the pectoral, second dorsal and
fins, bear a linear relationship to the length of
fish." For the length of the pectoral fin he u
the logarithm of fork length and for the other
fin dimensions he used the logarithm of both
length and fork length and simply states, with
offering proof, that these transformations are
propriate. Schaefer later (1952) cautioned
the relationships were only approximations
did not completely describe the relation betw

length and size of the body part. On the er hand, Godsil (1948: 7) stated—

otting to a large scale the actual measurements of a n character against body length in each case, revealed the sample regressions were nearly but not quite r. Of the various functions tried, the expression $a+bx+cx^{\frac{1}{2}}$ (where x=body length in each case and he dependent variable) resulted in the best fit.

other functions tried included $y=a+bx$, $a+bx+cx^2$, $y=a+bx+cx^2+dx^3$, $y=ax^b$, and $ae.^{bx}$ He also stated that the reduction in the of the squared deviations from the above ex- sion when compared with the sum from the ar regression was in most cases highly signifi- t. He offered no statistical data supporting assertion; but his graphs, with the plotted nts and curved lines, show clearly that the data head length and snout to the insertions of first sal, ventral, second dorsal, and anal fins are ntly curvilinear and the computed lines fit . The curvilinearity in Godsil's data is further zling because Schaefer and Walford (1950) sented data for characters used by Godsil that w no curvilinearity.

Therefore, it is desirable to examine in greater il the source of curvilinearity in Godsil's a. This may be done by comparing the mean- are deviations from linear regression with se from curvilinear regression (table 3). When n comparisons are summed for the 13 samples each character, I find that curved lines signifi- tly reduced the mean square of pooled data vell as the mean square of within-sample data each character. I notice, however, that for all characters reduction in the mean square from linear to curvilinear regression is much greater for pooled data than it is for within-sample data. Such differences between pooled and within-sample data suggest than a major part of the curvilinearity is between samples rather than within samples.

More conclusive evidence of the source of curvilinearity is to be found by examining the significance of the reduction in the mean square, character by character and sample by sample (table 3). Here significant or highly significant curvilinearity for most characters occurs in samples 1, 3, 4, 5, 6, and 7. In the remaining seven samples, 2 and 8 through 13, only four instances of a significant but not highly significant reduction in mean square occur in 35 comparisons. Since two significant reductions would be expected to occur by chance in this number of comparisons, little importance can be attached to the four. Clearly, curvilinearity is associated with certain samples and not with certain characters for all samples, as would be expected from a truly curvilinear regression of body part on fork length.

One characteristic of the samples that might be associated with curvilinearity is size, since it is obvious that very large samples (DF=385, 348) show curvilinearity whereas small samples (DF= 25, 36, 67) do not. Among the eight samples of intermediate size, however, four, with degrees of freedom equaling 192, 121, 98, and 96, show no more than one character with significant curvilin-

TABLE 3.—*Mean-square deviations from linear and curvilinear regressions of yellowfin morphometric measurements*

[Measurements from Godsil, 1948]

ample number	Degrees of freedom [1]	Length of head		Snout to insertion of—								Date of collection [2]
				First dorsal fin		Second dorsal fin		Anal fin		Ventral fin		
		Linear	Curvilinear	Linear	Curvilinear	Linear	Curvilinear	Linear	Curvilinear	Linear	Curvilinear	
	92	7.84	**6.69	14.53	**13.49	20.15	*19.22	20.26	**17.66	13.07	**11.41	Mar. 13, 1939.
	96	5.71	5.68	10.06	10.21	12.83	12.45	19.59	*18.47	11.89	11.79	Mar. 8, 1939.
	166	10.80	*10.58	12.40	12.10	21.17	**19.29	26.93	*26.44	16.87	17.10	Apr. 25, 27, 1940.
	385	11.06	**10.34	20.98	**19.70	32.46	**29.91	29.40	30.63	25.07	**24.70	Nov. 5 to Dec. 7, 1936.
	348	11.08	**8.91	18.97	**15.72	22.95	**15.59	22.63	**19.70	20.06	**19.07	Jan. 14 to Feb. 13, 1937.
	118	5.82	**5.32	10.66	**9.24	13.27	13.21	13.40	13.44	12.86	*12.32	Mar. 26, 27, 1939.
	141	18.40	**14.19	25.57	**22.22	38.00	**32.30	34.09	**30.69	31.75	**28.29	Jan. 16 to 19, 1937.
	192	7.73	8.37	12.01	12.49	11.62	12.55	16.56	16.85	14.07	15.71	Apr. 1 to 19, 1940.
	67	6.37	6.29	4.84	14.55	12.81	13.06	16.07	16.15	8.42	8.58	May 12, 1940.
	121	5.45	*5.26	9.91	10.30	11.19	11.03	15.74	16.43	13.79	14.16	Jan. 21 to Feb. 10, 1937.
	36	7.81	7.83	9.94	*8.83	21.92	21.03	13.97	14.17	18.63	19.32	Mar. 22 to 24, 1940.
	25	6.92	7.21	7.84	8.17	15.16	15.75	23.60	24.54	21.12	21.96	Apr. 29, 1940.
	98	8.28	8.32	14.99	15.11	13.04	*12.66	16.72	16.84	14.27	14.28	Mar. 30, 31, 1940.
d-sample variance	1909	12.07	**9.53	19.07	**15.78	24.93	**20.40	27.25	**25.85	19.91	**19.31	
in-sample variance	1885	9.71	**8.80	16.14	**14.94	21.69	**19.24	22.65	**21.99	18.73	**18.34	

[1] Varies slightly with different characters. [2] Supplied by Godsil in personal communication. * Statistically significant reduction in mean square ($>p>0.01$). **Highly significant reduction in mean square ($p<0.01$).

earity. The other four samples of intermediate size show highly significant curvilinearity in at least one character and significant curvilinearity in more than half of the characters. It is likely that something other than sample size alone has caused curvilinearity.

Another source of curvilinearity may be accidents of sampling. Such accidents appear to be rather likely because most of Godsil's samples (table 2) were obtained on a single day or over a period of a few days. It is well-known that yellowfin school by size, and when one of the larger samples includes a considerable range in sizes it is probable that it was obtained from only a few schools of different average size. If the sample included schools of slightly different morphological characteristics and also of different mean size, there would be two sources of regression—one within schools fished and the other between schools fished. The combined regressions might appear to be curvilinear.

Therefore, when I examined our data for curvilinear regression I turned first to the sample that I considered had the best coverage of the area sampled and that contained a good size distribution of fish. It was the sample from the western Line Islands area, obtained during 13 different months with the majority of the fish caught by longlining and trolling and measured by 12 different measurers. During both longlining and trolling operations, it was customary to measure only a few fish a day (rarely more than 10), and thus these fish came from several dozen different schools and as many different locations within the area. There are 188 sets of measurements available in this sample, with good numbers in most 10-cm. length groups from 50 to 160 cm.

Evidence of curvilinearity was sought in the plots of complete data that were made to check each sample. Some evidence of curvilinearity appeared in the plots for certain characters, but the scatter of points around the line made interpretation difficult. Hence, I sought a way to magnify any curvilinearity and plotted the deviations of the 10-cm. group means from the rectilinear regression equations for each character in the sample (fig. 4). These equations were based on the transformations, proposed by Schaefer (1952), which are log fork length and log height of second dorsal fin, log fork length and log height of anal fin, and log fork length and length of pectoral fin.

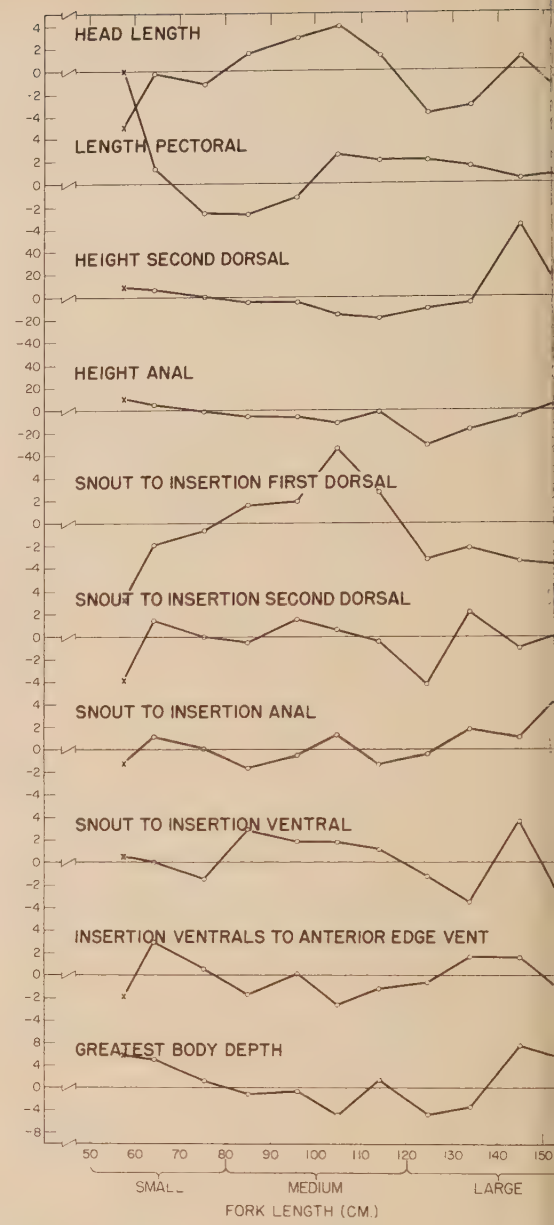


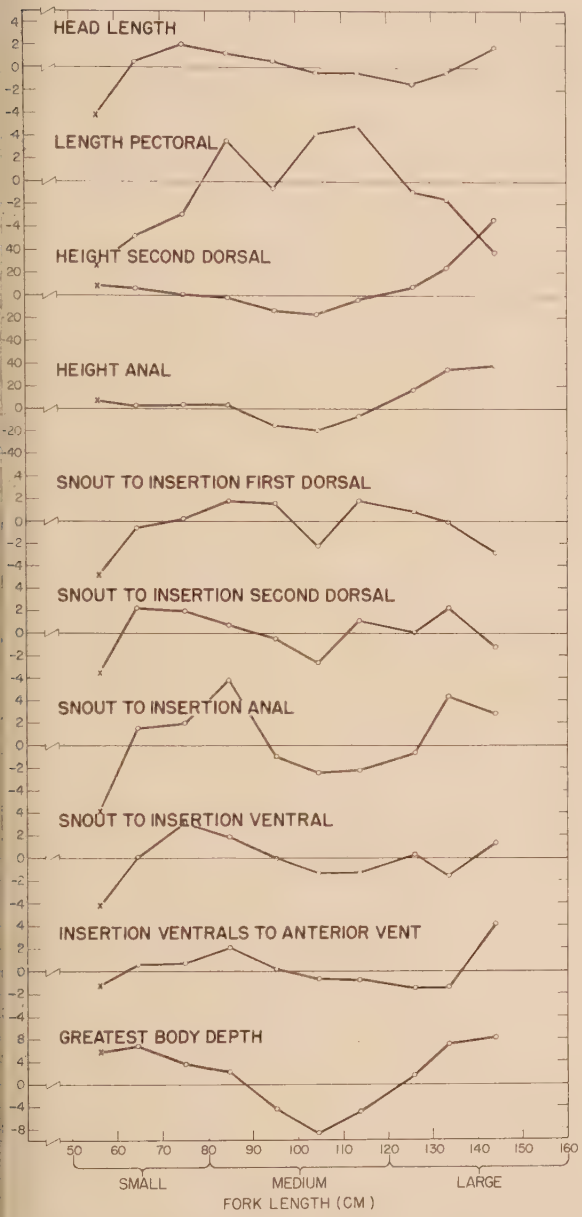
FIGURE 4.—Sample of yellowfin tuna from western Islands area. Deviations of 10-cm. group means f regressions were used. (X, average of less than 10 0, average of 10 or more fish.)

The data for all other characters were not tra formed.

The graph suggests that some curvilinea occurs in several characters. If a random tribution of 10-cm.-group means about the gression line is assumed, a line connecting group means would be expected to cross the gression line an average of five times (with points). To the contrary, for four character

gth of pectoral, height of second dorsal fin, ght of anal fin, and snout to insertion of first sal fin—the lines crossed only twice. In the e of only one character—the snout to insertion second dorsal fin—did the lines cross more n the most probable number of times.

The question then arose whether the curvilinty prevailed in other samples, and I made a ilar analysis of our other two large samples



URE 5.—Sample of yellowfin tuna from central Caroline lands area. Deviations of 10-cm.-group means from gression. (X, average of less than 10 fish; 0, average of) or more fish.)

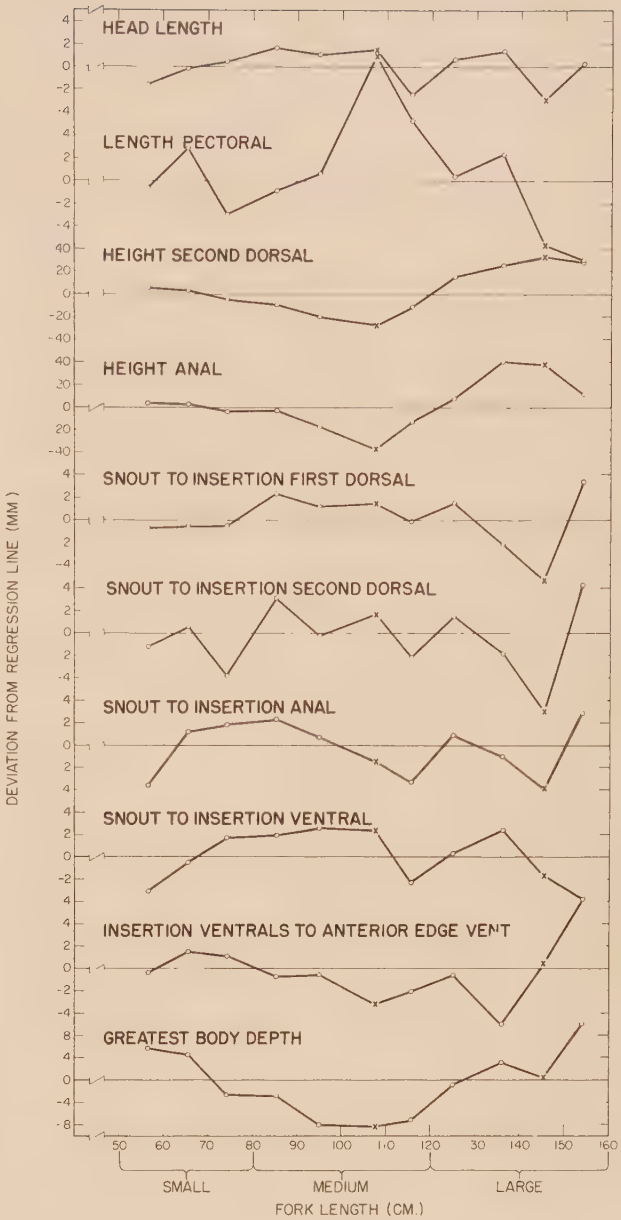


FIGURE 6.—Sample of yellowfin tuna from eastern Caroline Islands area. Deviations of 10-cm.-group means from regression. (X, average of less than 10 fish; 0, average of 10 or more fish.)

that also are well distributed over a wide range of lengths. They were the samples from the eastern Caroline Islands and the central Caroline Islands, which contained 171 and 211 sets of measurements, respectively. Similar plots of deviations of 10-cm.-group means from the rectilinear regression lines (figs. 5 and 6) indicated

again that the lines cross less than the expected number of times for most characters.

When compared, the deviations from regressions of all three areas indicate that they tend to form a curve concave upwards for height of second dorsal fin, height of anal fin, and greatest body depth. Other characters, especially head length, snout to insertion of first dorsal fin, and snout to insertion of ventral fin, appear sinuous with some tendency for the line connecting means to start below the regression, then go above, then below, and then upward again. The line appears to be curved for length of the pectoral fin, but in a different way in each sample.

I conclude that for most characters in these large samples some curvilinearity remains that is not associated with sampling, but is rather an expression of the allometric growth of the fish. Furthermore, it is an irregular allometry which is not readily expressed by any linear or simple curvilinear formulation.

Such curvilinearity would not be troublesome if all samples had similarly distributed lengths, in which case it would probably be satisfactory to use the regression techniques proposed by Schaefer (1948). The rather small amount of curvilinearity would result in some bias in mean, variance, and regression constants, but if such bias were similar among samples it would not matter. However, it has not been possible to obtain samples covering a uniform range of lengths. In numerous areas, particularly along the Pacific Equator, where we have fished only with longline gear, we have obtained only very large fish, and in other areas, where fishing has been done only by trolling, we took mostly small fish.

The compromise solution has been to split the samples into three size groups and compare them at three different standard lengths, each very close to the grand mean of its size group. The following groups have been used:

Small (S)—fish less than 80 cm., most of which are more than 50 cm. and which have been compared at a length of 65 cm. (about 12 lb.); medium (M)—fish from 80 to 120 cm., compared at a length of 100 cm. (about 43 lb.); large (L)—fish more than 120 cm., most of which are less than 170 cm. and which have been compared at a length of 140 cm. (about 118 lb.).

Further restrictions were adopted: first, to avoid uncertainties due to the small samples it was required that there be more than 20 specimen each size group, and second, to minimize effect of any curvilinearity remaining withi size group, it was required that more than percent of the sample be above and more t 10 percent below the comparison size. For ample, in Godsil's sample from Panama and C Rica there were 23 fish between 120 and 140 and none above 140 cm. This part of his san was not considered in the large group, whereas sample from Cocos Island including 23 fish rang from 120 to 160 cm., with 9 above 140 cm., considered. One sample remains that is not distributed in fork length—the one from north Africa. It has been used, but the comparis are made with reservations.

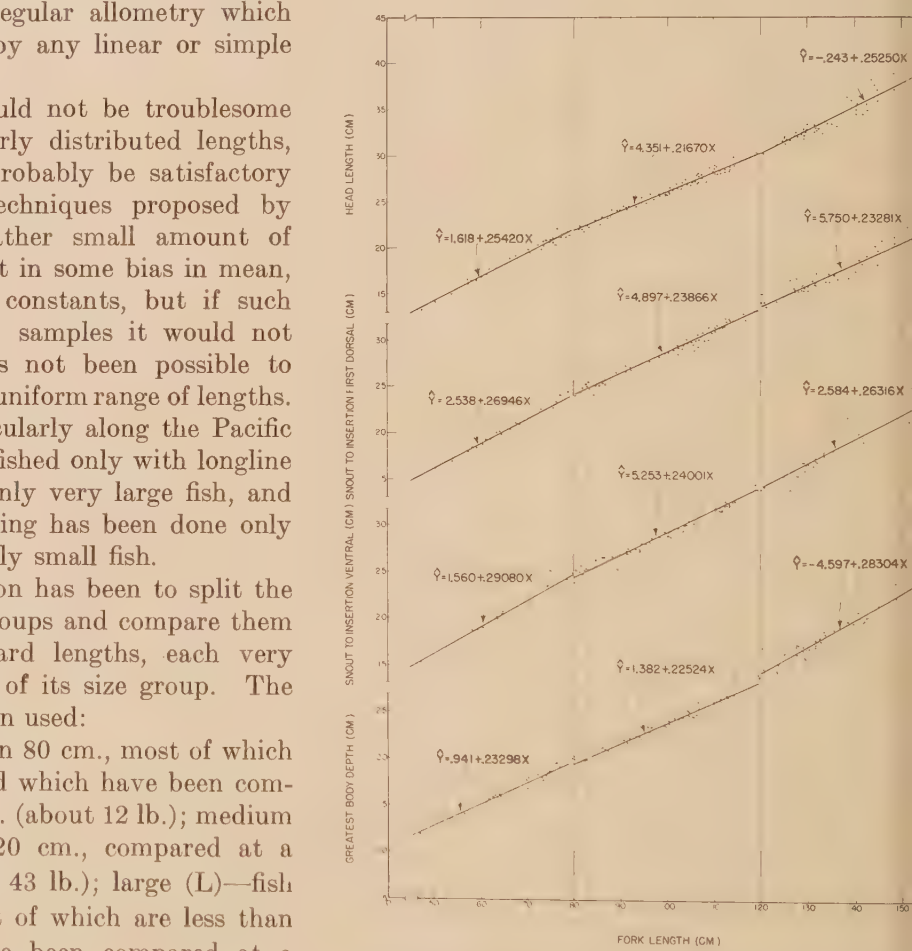
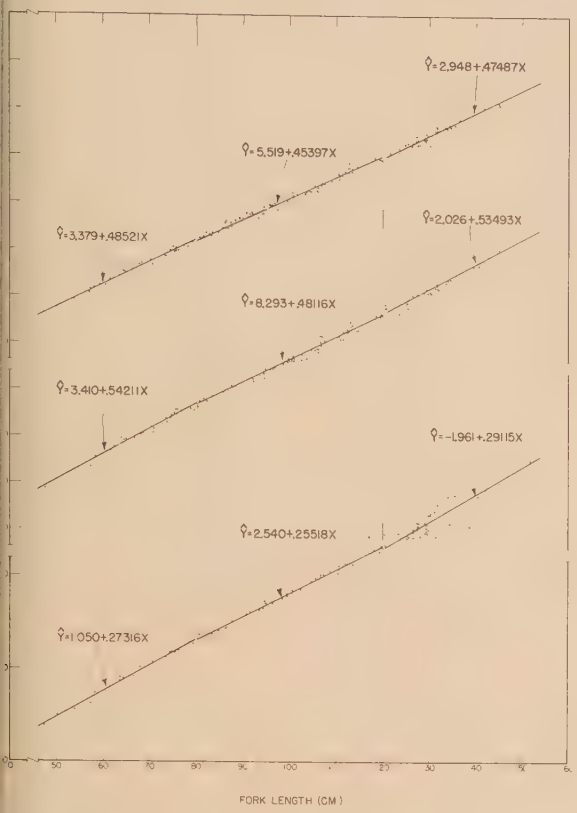


FIGURE 7A.—Regressions of head length, distances snout to insertions of first dorsal and ventral fins, greatest body depth in yellowfin tuna from ce Caroline Islands area.

'he fit of the lines to the three size groups may judged from the plots of the data from the tral Carolines area (figs. 7A, 7B, and 7C). h of the three separate lines appears to be a



URE 7B.—Regressions of distances from snout to sertion of second dorsal and anal fins and distance om insertion of ventral fin to anterior edge of vent, in ellowfin tuna from central Caroline Islands area.

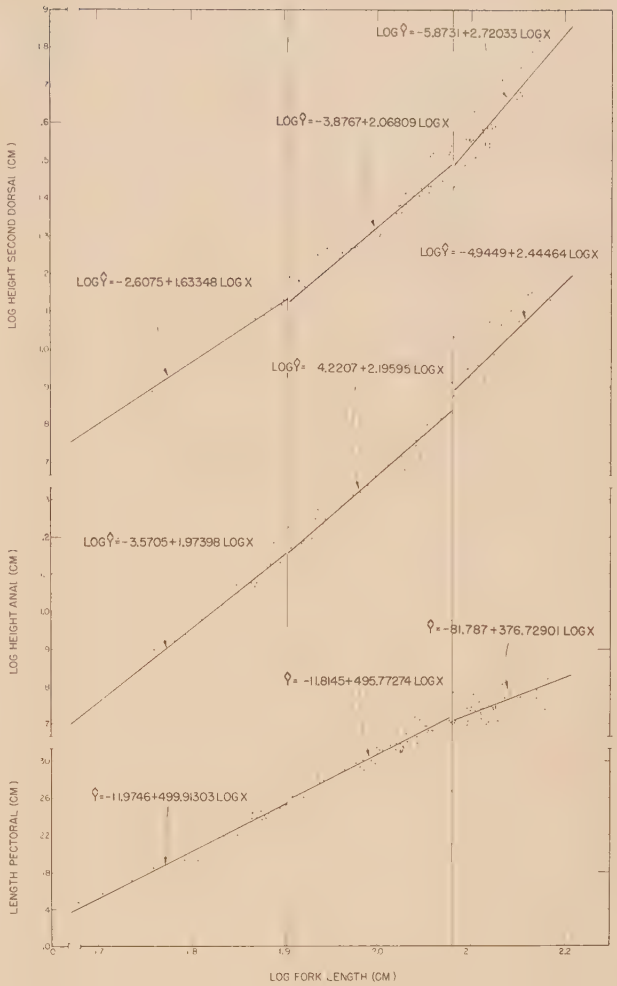


FIGURE 7C.—Regressions of log heights of second dorsal and anal fins and length of pectoral fin, in yellowfin tuna from central Caroline Islands area.

d fit in its limited range, but when projected ond the range it may rapidly diverge from the tted points. The tendency that has been noted ard a sinuous line in certain characters is in evidenced in the plots and in the changing ression constants. I judge, however, that any aining curvilinearity within each size group much less than the dispersion of points about line and that samples within each size group y be compared with little fear of erratic results e to curvilinear regression.

LIABILITY OF SAMPLE STATISTICS

n addition to determining methods of re-ssion analysis that will give reliable estimates mean and variance the reliability of the raw a must be assessed. Two matters may be examined: first, the adequacy of the sampling, and second, the accuracy of the measurements.

An ideal sample of yellowfin tuna for a morphometric study would be representative of all sizes of tuna in the specified area during the period of study. Such a sample would contain a distribution of sizes proportionate to the numbers of each size in the ocean and would be randomized over the time and area covered. This ideal is far out of reach because it is not possible to catch all of the sizes, as each fishing gear selects certain size groups, and it has not been possible to fish any area at randomly selected locations or times.

Consideration of the habits of the yellowfin suggests, however, that satisfactory samples may be obtained from a relatively limited coverage.

The yellowfin is a schooling species (Murphy and Elliott, 1954), and I have suggested that schools in a limited area may vary slightly in their morphometric characteristics (p. 406). The yellowfin are fast swimmers, however, and it seems probable that they could cover hundreds of miles in a few days. Furthermore, the larger yellowfin at least are entirely independent of coastal regions. The ocean in which they are found is relatively uniform, with no absolute barriers to migration, although the yellowfin do prefer certain areas, presumably where they find the most food. So it is possible that a sample made up of subsamples from numerous, different schools may be adequately representative of an area even though the area is not randomly covered. The schools may be assumed to have been randomly swimming in the area. A similar assumption with regard to time is less safe because many species migrate annually, and even if yellowfin are present in an area throughout the year, they might be different spawning groups.

Even though the ideal sample cannot be obtained, samples with widely varying coverage in area and time (table 2) may be compared. As the samples were extended in space and time, however, they were taken by an increasing number of people, who may have varied in their techniques of measurement. Therefore, the problems of sampling and precision in measuring the fish must be considered simultaneously, and here I digress briefly to consider the problem of obtaining consistent measurements of yellowfin.

Fortunately, all tunas are easy to measure consistently. The body is stiff, and even when not in rigor mortis has almost no tendency to bend when the fish is laid on a flat deck on its side. The parts to be measured were accurately defined by Marr and Schaefer (1949). The numerous measurers from POFI have compared their methods—almost no one measured tuna without first working with someone who had measured them before—and most differing interpretations of the definitions have been quickly settled. Nevertheless, I consider that minor differences of technique must have occurred both among POFI and other measurers, and the problem is to assess how great the differences have been.

One approach to this problem might be to have different people repeat measurements on the same fish and then analyze the differences. We have made repeat measurements to standard our methods but have not analyzed the differen because our concern is with what people have d independently and routinely and not what t could do under experimental conditions.

It will not be possible to separate the differen in technique from differences of time and a but the combined problem can be approached examining the variance in relation to coverage the sample and number of measurers. Also m values and overlap of closely related samp obtained by different measurers can be compar The latter comparison must be left until I h introduced the method of comparing means overlap.

The variance itself is not suitable for comparison. Better is the standard deviat from regression $S_{y.x}$, which is directly indicat of the spread of points about the line, but obviously is related to the size of the charac even when the characters have been transform to logarithms. So I have used a kind of coeffici of variation,

$$C=\frac{100\ S_{y.x}}{\bar{x}},$$

to eliminate the effect of size of character $\bar{x}$ so obtain a better mean value for all characters a sample.

These coefficients of variation have b computed for each character in each sample are shown in table 4 (except the samples Godsil (1948) from Panama and Costa Rica from Cocos Island, in which his curvilin regressions were used and in which the ra spreads extensively over two or more of our groups).

Several samples contained measurements only five characters, and hence the sample me and the grand means were computed from th five characters only.

This table shows close agreement among gr means of the coefficients of size groups for five characters, which indicates that the stand deviation from regression is almost exac related to size of the fish. Further, there is sc difference among characters: length of pect fin and greatest body depth have a high coefficie log heights of second dorsal and anal fins sh coefficients that increase with size of fish; distan from snout to insertion of second dorsal and a fins have the lowest values.

TABLE 4.—*Coefficients of variation of yellowfin morphometrics*

Area and size [1]	Length of head	Length of pectoral fin	Weight of second dorsal fin	Weight of anal fin	Snout to insertion of—				Greatest body depth	Insertion ventral to anterior edge vent	Means [2]
					First dorsal fin	Second dorsal fin	Anal fin	Ventral fin			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	
ico: [3] S	1.38				1.70	1.05	1.04	1.60			1.35
temala: [3] S	1.32				1.64	1.06	.96	1.76			1.35
a Rica: [4] M	1.75	3.13	1.67	1.85	1.76	1.38	.95		3.14		1.46
apagos Island: [3] S	1.42				1.61	.92	.99	1.71			1.33
perton Island: [3] S	1.33				1.36	1.18	.85	1.83			1.31
-119° W.: L	1.94	3.58	1.32	2.55	3.03	1.44	1.10	2.35	2.19	2.88	1.97
-129° W.: L	2.20	4.68	2.58	2.53	2.01	1.18	1.38	2.90	4.29	2.80	1.93
-139° W.: L	1.16	4.17	2.66	2.58	2.07	1.33	1.24	2.04	4.09	2.61	1.73
-149° W.: L	1.81	3.50	2.47	2.60	2.23	1.28	1.33	2.14	2.96	2.72	1.76
Line Islands:											
M	1.57	3.03	2.50	2.34	2.02	1.34	1.63	1.84	3.24	2.27	1.68
L	1.82	4.05	2.57	2.71	2.44	1.62	1.33	2.55	2.51	2.54	1.95
t Line Islands:											
S	2.28	3.77	1.56	1.55	2.63	1.34	1.63	2.53	3.43	2.65	2.08
M	2.16	4.40	2.15	2.84	2.27	1.48	1.55	2.70	4.19	2.23	2.03
L	1.96	2.88	2.44	2.26	1.76	1.29	1.11	1.94	3.19	2.64	1.61
ayra Island: [5]											
S	2.02				2.64	1.38	1.24	1.58			1.77
M	1.57				1.86	1.36	1.59	1.72			1.62
enix Islands:											
S	2.33	4.09	1.63	1.80	1.85	2.20	1.50	2.53	2.59	2.15	2.08
M	2.30	4.45	2.02	2.59	2.00	2.49	1.70	2.57	4.10	1.99	2.21
L	1.93	3.22	2.22	1.97	2.09	1.37	1.32	2.80	3.73	2.53	1.90
Marshall Islands: L	1.45	3.78	2.08	1.97	1.41	1.03	1.04	1.58	2.54	2.57	1.30
ni Island: S	1.51	3.30	1.28	1.58	1.78	.84	1.10	2.41	2.18		1.53
Caroline Islands:											
S	1.34	4.04	1.25	1.49	2.04	1.21	1.19	1.75	2.83	2.50	1.51
M	1.25	3.79	1.34	1.49	1.66	.93	.87	1.78	2.68	2.28	1.30
L	1.60	3.27	1.98	1.66	2.22	1.10	1.11	1.90	3.23	2.04	1.59
tral Caroline Islands:											
S	1.64	3.01	.90	1.50	1.61	1.37	1.74	3.14	3.32	2.93	1.90
M	1.31	3.91	1.52	1.56	2.05	1.41	1.52	2.48	2.93	2.51	1.75
L	1.97	3.63	2.46	2.07	2.23	1.48	1.52	3.13	3.72	3.13	2.07
ippines:											
S	2.14				2.82	2.49	2.02	2.50			2.39
M	2.37				2.31	1.62	1.55	2.30			2.03
L	2.74				3.11	1.87	2.25	3.62			2.72
n: S	1.78	3.65	1.32	1.49	2.01	1.34	1.11	2.16	2.91		1.68
aii:											
S	1.77	4.87	1.75	1.79	2.17	1.51	1.56	2.77	3.70		1.96
M	2.19	5.04	1.95	2.55	2.65	1.37	1.49	2.72	3.42		2.08
L	1.74	3.84	2.20	2.13	2.01	1.41	1.26	2.04	3.36		1.69
aii: [5]											
S	1.52				1.70	1.01	1.05	1.98			1.45
L	1.32				2.03	1.20	1.05	1.51			1.42
ty Islands: S	1.49	4.12	1.60	1.97	2.42	1.43					1.78
heast Africa: S	2.19	3.90	1.53	2.08	2.92	1.93	1.87	2.98	2.52		2.38
ola, Africa: [6]											
M	1.88	3.98	1.33	1.47	2.29	1.39	1.46	1.62			1.73
L	1.90	3.58	1.86	2.36	2.24	1.19	1.46	1.72			1.70
Means:											
	1.72	3.86	1.42	1.69	2.06	1.39	1.32	2.22	2.94	2.56	1.74
	1.84	3.97	1.82	2.09	2.09	1.48	1.43	2.19	3.39	2.26	1.81
	1.88	3.68	2.24	2.28	2.21	1.34	1.32	2.30	3.26	2.65	1.81

S, fish less than 80 cm., and compared at a length of 65 cm.; M, fish from 80 to 120 cm., and compared at a length of 100 cm.; L, fish more than 120 cm., compared at a length of 140 cm.

[2] Mean of columns (1), (5), (6), (7), and (8). [3] Godsil (1948) and in correspondence. [4] Schaefer (1952). [5] Godsil and Greenhood (1951). [6] Schaefer Walford (1950).

Of most interest, however, is the rather small ount of variation in the mean C values for the ferent samples. These values range from a of 1.30, equal in the eastern Marshalls group and the eastern Carolines group M, to a high 2.72 in the Philippines group L. The Philipes group S and the northeast Africa group S next highest. (I have no information on how se samples were collected and the factors that y have caused the higher values.) Among the FI samples the highest (2.21) value is found the Phoenix Islands group M.

When I tried to relate the mean C to the number measurers and to the coverage of the sample in figure 8, I found little relation. The grand mean for one to three examiners is 1.62; for four to six examiners, 1.88; and seven or more, 1.92. The relation to length of sampling period is similar: for 1 to 9 days the mean is 1.64; for 10 to 19 days, 1.91; and for 20 or more days, 1.80.

None of this evidence is conclusive, but there appears to be a slight increase in the value of C, which is associated with increased time, greater number of measurers, or greater area sampled. I cannot segregate these factors, but because curvilinearity appears in some of Godsil's (1948) samples which were collected during only a few days, the samples taken on fewer than 10 different

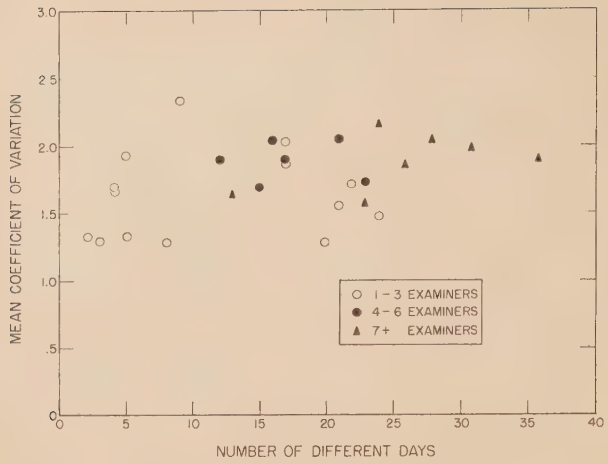


FIGURE 8.—Relation of the mean coefficient of variation of five selected characters to number of examiners and number of days on which parts of the sample were taken.

days may be less representative. Therefore, I conclude that important bias was not introduced by different techniques among measurers, at least not in the central and eastern Pacific area, where all of the measurers worked closely with one another.

CHARACTER-BY-CHARACTER COMPARISON OF SAMPLES

One of the most direct and useful ways of comparing morphological data is simply to compare the mean values estimated for certain fixed lengths. These values are particularly useful because they may be associated readily with geographic features and show directly the presence of character gradients or clines. Unlike tests of significance or amounts of overlap, an examination of the means shows directly the differences in number of parts or in body form. Of course, with all characters associated with body size it is necessary to control body size by the use of appropriate regressions.

A first comparison of samples is logically among the considerable series available from the equatorial Pacific. Areas from which these samples came extend from the American coast westward about 8,400 miles to the central Carolines area, which is bounded on the west by longitude 140° E. (fig. 2). This area of comparison is limited to the region between latitude 10° N. and latitude 10° S., although some of the samples are more restricted than this in latitudinal coverage. the southern and extreme northern parts of zone are the westerly flowing South Equatorial North Equatorial Currents. Between these currents (5° N. to 10° N.) is the easterly flow Countercurrent. Throughout this area [6] yello tuna have been taken near the Equator and h been found to be especially abundant between Equator and the Countercurrent. They have been found to be rather consistently sc north of the Countercurrent and south of Equator. They do, however, occur well to north and south of this equatorial region, and known barriers to their horizontal migration e in any direction until water too cold for t liking is reached in the vicinity of latitude N. or S.

So we know that the distribution of yellowfi continuous from east to west in this equato band and that the tuna prefer a band about miles wide in a north-south direction. Here situation where character gradients may be pected if the tuna are not freely interming across the whole equatorial Pacific.

In order to seek gradients I have adopte slightly modified form of the method proposed Hubbs and Hubbs (1953). Theirs is a graph method in which the mean is plotted, a measur dispersion is indicated by one standard deviat plotted on either side of the mean as a hollow and a measure of reliability is indicated by standard errors of the mean plotted as a solid on either side of the mean. The range is indic by a base line. I have used comparable regress statistics, except for the range. First, the m part size $\hat{Y}$ was calculated directly from the reg sion equation

$$\hat{Y}=a+bX.$$

Second, the dispersion around the regression is indicated by one standard deviation from reg sion

$$S_{y\cdot x}=\sqrt{\frac{\Sigma y^2-(\Sigma xy)^2/\Sigma x^2}{n-2}}$$

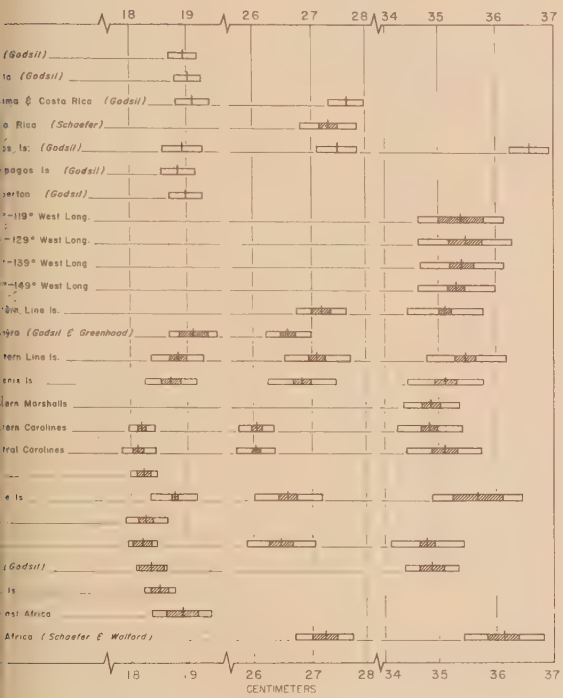
plotted as a hollow bar on either side of the me The reliability of the mean is indicated by

[6] In the gap between longitude 109° W. and the American coast (f yellowfin have been taken by commercial vessels and research ships spo by the Inter-American Tropical Tuna Commission.

dard errors of the mean estimated from regres-

$$2S_{\hat{y}\,.\,x}=2S_{y.x}\sqrt{1/n+x^2/\Sigma x^2}$$

ed as a solid bar on either side of the mean. ese statistics were computed separately for size group in each sample. For the small roup they were computed at a fork length of n., for the medium (M) group at 100 cm., and ne large (L) group at 140 cm. The three size os are shown separately for all samples in es 9 to 18. In each graph the equatorial ic samples are arranged in order from east to and the other samples are added at the bottom.



RE 9.—Head length of small (65 cm.), medium (100 .), and large (140 cm.) yellowfin tuna, as estimated m regression statistics. (The center line indicates e mean, solid bar ± two standard errors of the mean, llow bar ± one standard deviation from regression.)

most all of the characters show gradients—etimes stepped, sometimes continuous, and etimes confused, perhaps because differences small and sampling variation has its effect. gradients, however, in most cases are istakable.

here is a distinct tendency toward shorter ls (fig. 9) in all three size groups from the ern Pacific. The gradient is not smooth, because fish of the large group from longitude 109° W. to the western Line Islands area have much the same size head, and head size in the samples from the medium and small groups is much the same near the ends of the range.

The length of the pectoral fin (fig. 10) is distinctly greater in fish from the Caroline Islands area than in those from the eastern Pacific. Again similar tendencies occur in all size groups except

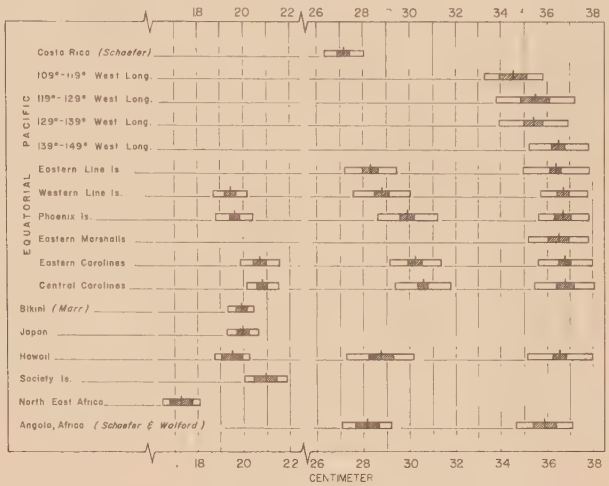


FIGURE 10.—Length of pectoral fin of small (65 cm.), medium (100 cm.), and large (140 cm.) yellowfin tuna, as estimated from regression statistics. (The center line indicates the mean, solid bar ± two standard errors of the mean, hollow bar ± one standard deviation from regression.)

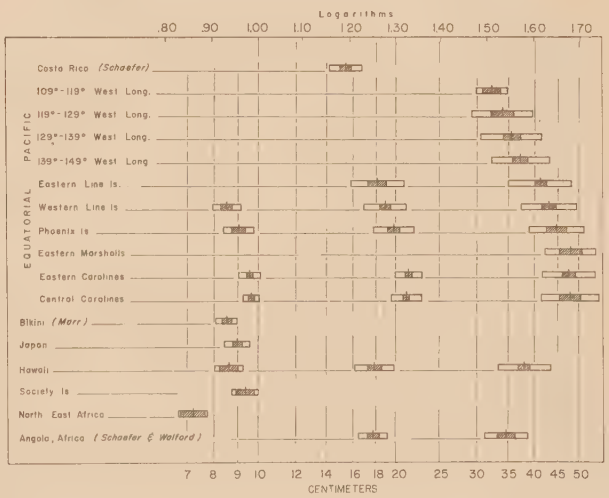


FIGURE 11.—Height of second dorsal fin of small (65 cm.), medium (100 cm.), and large (140 cm.) yellowfin tuna, as estimated from regression statistics. (The center line indicates the mean, the solid bar ± one standard deviation from regression.)

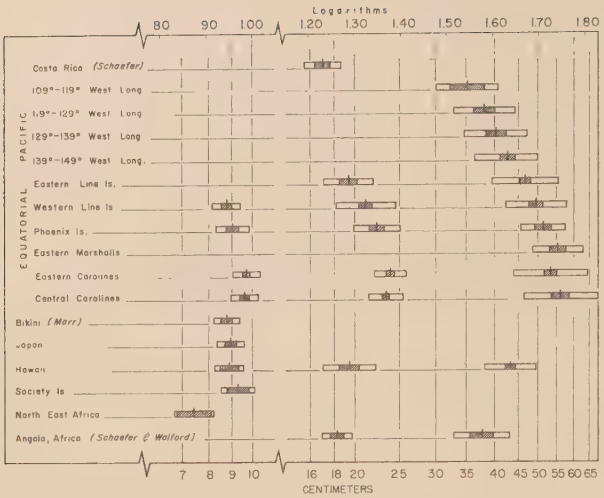


FIGURE 12.—Height of anal fin of small (65 cm.), medium (100 cm.), and large (140 cm.) yellowfin tuna, as estimated from regression statistics. (The center line indicates the mean, the solid bar ± two standard errors of the mean, the hollow bar ± one standard deviation from regression.)

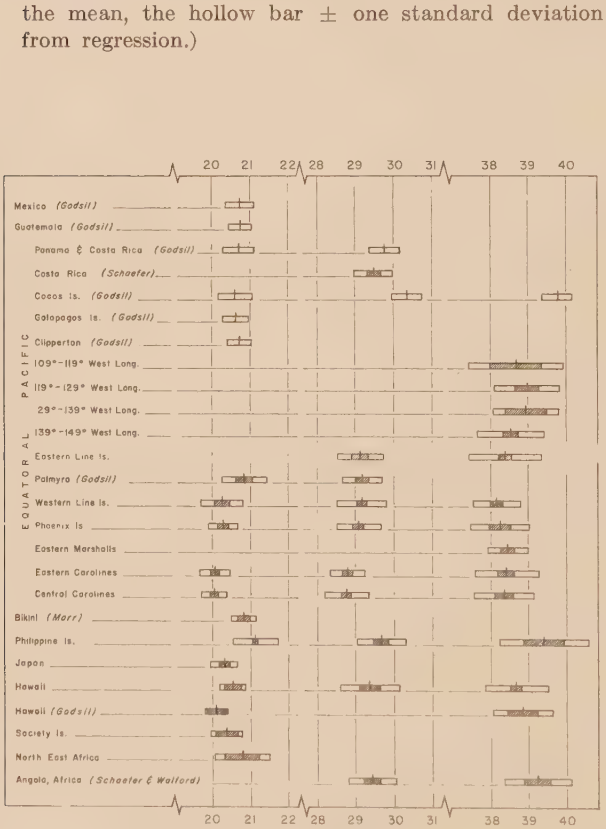


FIGURE 13.—Distance from snout to insertion of first dorsal fin of small (65 cm.), medium (100 cm.), and large (140 cm.) yellowfin tuna, as estimated from regression statistics. (The center line indicates the mean, the solid bar ± two standard errors of the mean, the hollow bar ± one standard deviation from regression.)

that both the small and medium groups sugg
rather smooth cline, whereas the large g
shows a rather similar fin length from longi
139° W. to the Caroline Islands.

The differences in the height of the ana
(fig. 12) and the height of the second dorsa
(fig. 11) are even more marked, with clear
almost uniform gradients from the vicinit
Costa Rica to the eastern Marshalls and
about the same length fins on through the Car
Islands area. Here the difference among sam
of the large size group is about 16 cm. for he
of second dorsal fin and 20 cm. for height of
fin from longitude 109° W. to the Caroline Isla

The distance between the snout and the
sertion of the first dorsal fin (fig. 13) sho
distinct but somewhat irregular trend in
opposite direction, with the fish in the eas
Pacific having the greater measurement betw
these two points. In all size groups, insofa
samples are available, clearer trends in the s
direction are to be noted in the measurem
between the snout and the insertion of the se

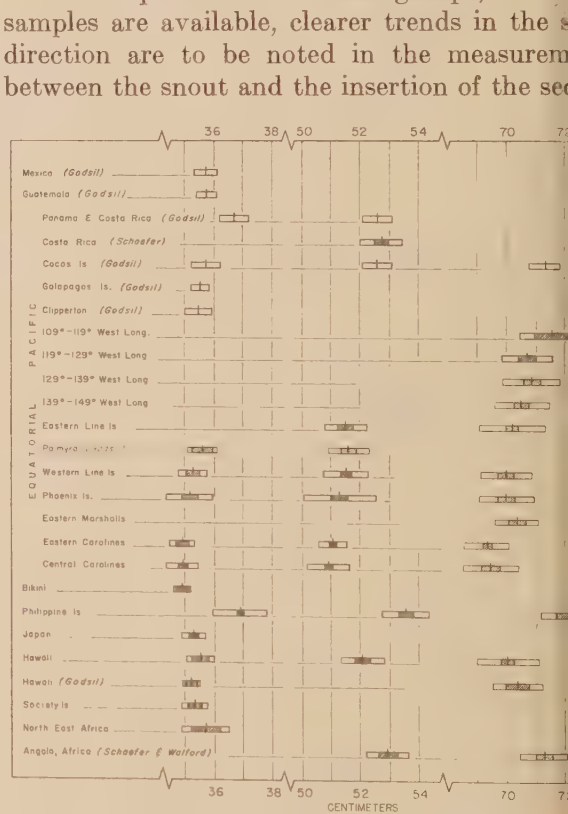
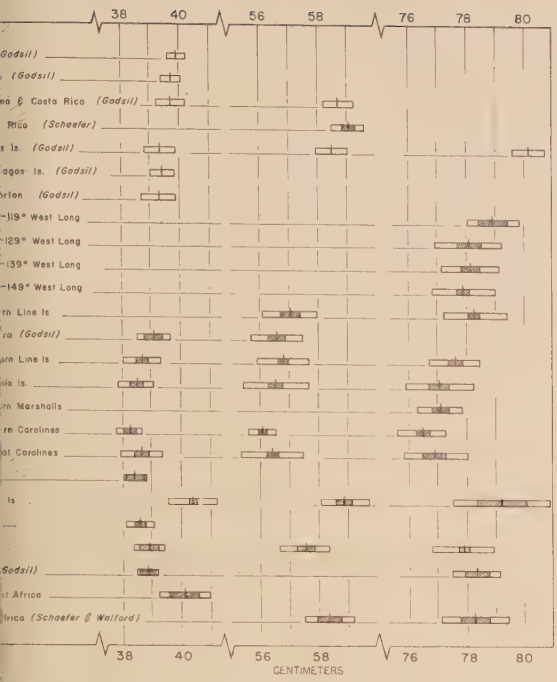


FIGURE 14.—Distance from snout to insertion of se
dorsal fin of small (65 cm.), medium (100 cm.),
large (140 cm.) yellowfin tuna, as estimated fro
gression statistics. (The center line indicates
mean, the solid bar ± two standard errors of the
the hollow bar ± one standard deviation
regression.)



RE 15.—Distance from snout to insertion of anal fin small (65 cm.), medium (100 cm.), and large (140 .) yellowfin tuna, as estimated from regression sta- ics. (The center line indicates the mean, the solid ± two standard errors of the mean, the hollow bar one standard deviation from regression.)

al fin (fig. 14) and between the snout and the tion of the anal fin. In the large fish the l is especially clearcut for the snout to in- on of anal fin (fig. 15). The snout to insertion ntral fins (fig. 16) shows a somewhat similar ency, but again the differences are smaller sampling variation causes some confusion. remaining characters, distance from the tion of the ventral fins to the anterior edge e vent (fig. 17) and greatest body depth (fig. present a more confused picture. In the um-sized fish there is a tendency for the fish the eastern Pacific to have a greater body n, but this tendency is not so noticeable ng the larger specimens. The distance from entral insertion to the anterior edge of the divides the samples into two groups. The nce is about 40 cm. in the large size group ng all samples from between longitudes 109° nd 149° W. and about 39 cm. in the samples the eastern Line Islands to the central line Islands area.

early, then, a more or less steady cline from eastern to the west-central Pacific exists,

with the average yellowfin in the eastern Pacific having the larger head, shorter pectoral, second dorsal, and anal fins, and greater distances from the snout to the insertions of first dorsal and ventral fins. It also has considerably the greater distances from the snout to the insertion of the second dorsal and anal fins, a greater body depth, and greater length from the ventral fins to the vent. Evidently, these greater distances to the insertions of the second dorsal and anal fins mean a correspondingly shorter caudal peduncle.

When this series of samples from the equatorial Pacific is compared with other samples from the more temperate waters some surprising differences are found. In the Bikini Island sample, which came from just outside the equatorial area at latitude 12° N., the fish would be expected to resemble those from the nearby Caroline Islands to the southwest, but they had especially short second dorsal and anal fins and a greater distance from the snout to the insertion of the first dorsal fin. The Bikini fish were small and were taken by trolling close to the island. In many regions of the Pacific these small yellowfin appear to be

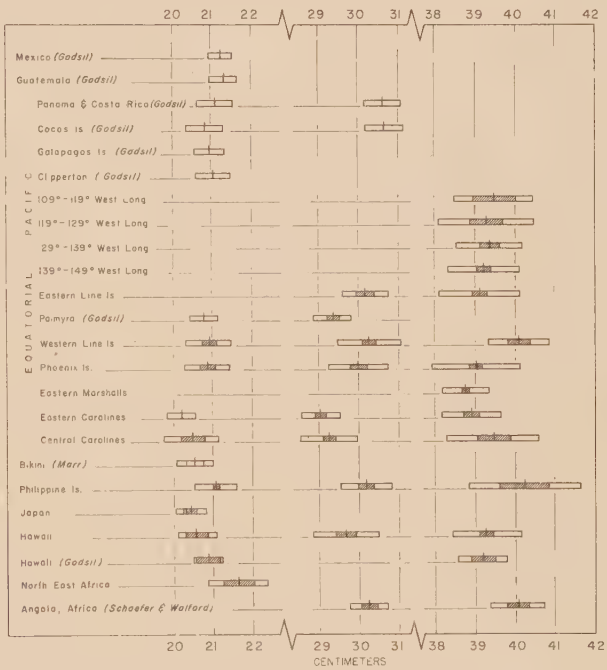


FIGURE 16.—Distance from snout to insertion of ventral fins of small (65 cm.), medium (100 cm.), and large (140 cm.) yellowfin tuna, as estimated from regression statistics. (The center line indicates the mean, the solid bar ± two standard errors of the mean, the hollow bar ± one standard deviation from regression.)

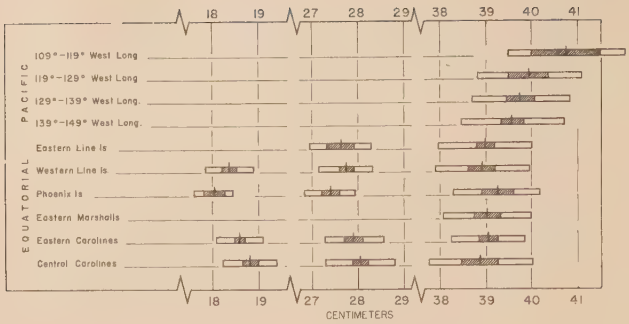


FIGURE 17.—Distance from insertion of ventral fin to anterior edge of vent of small (65 cm.), medium (100 cm.), and large (140 cm.) yellowfin tuna, as estimated from regression statistics. (The center line indicates the mean, the solid bar ± two standard errors of the mean, the hollow bar ± one standard deviation from regression.)

FIGURE 18.—Greatest body depth of small (65 cm.), medium (100 cm.), and large (140 cm.) yellowfin tuna, as estimated from regression statistics. (The center line indicates the mean, the solid bar ± two standard errors of the mean, the hollow bar ± one standard deviation from regression.)

common in the vicinity of islands and are very rarely taken on longlines. So this group of small fish near Bikini may be a relatively isolated one.

Characteristics of the sample from the Philippines are particularly surprising, because in all of the characters examined the fish are much more like those of the eastern Pacific than those of the nearby Caroline Islands area. This is consistently true for all size groups in all characters. Further, in the distance from the snout to the insertion of the first dorsal fin and also to the second dorsal, the means for the Philippine sample are distinctly larger than for any other samples.

The sample from Japan consisted only of s fish and in all respects is remarkably like groups sampled from Hawaii. In not a s character is the difference of the means g enough to separate the dark bars that repre twice the standard error of the mean and, h indicate a statistically significant difference tween the means.

The samples from Hawaii show some mixed relationships with those from the equat area. In head length they are similar to t from the Caroline Islands, whereas in lengt fins and in the distances from snout to inse of the second dorsal and anal fins they are n more like the yellowfin of the equatorial southeast of Hawaii between longitudes 129° 159° W.

The sample of small yellowfin from the So Islands was measured after being landed thawed in Honolulu. Such handling may changed the dimensions and this sample may be directly comparable to the others. For reason this is not a satisfactory sample. however, near the Phoenix Islands sample in length, height of the anal fin and distances snout to first and second dorsal fins, but it h very short second dorsal fin and much lo pectoral and anal fins than any other sample

The sample from off Somaliland in north Africa is the most diverse of the group. It is lar to one or more central Pacific equatorial ples in head length and distances from snou insertion of first and second dorsal fins, but it very short pectoral, second dorsal, and anal Somaliland fish also have a very long distance the snout to the insertion of the anal fin, an e cially deep body, and a long distance from snout to the insertion of the ventral fins. sample is very different from the sample from west coast of Africa taken near Angola, where fish are remarkably similar to those of the eas Pacific in most dimensions. The yellowfin Angola differ from those from Costa Rica pr pally in having slightly longer fins (as was poi out by Schaefer and Walford, 1950).

In summary, yellowfin from the Pacific sh continuous cline morphologically along the E tor, whereas the samples taken in areas dis from the Equator differ erratically from the e torial cline. The dimensions, however, are w the range of characters in the equatorial clin

so close to one of the ends of the cline that appears to be no evidence of genetically isostocks in the Pacific. This evidence will be dered further after data on overlap have been ssed.

MPARISON OF SAMPLES FROM THE SAME AREA

mples by Godsil (1948) and Godsil and Green- (1951) were obtained from areas also sampled chaefer and Walford (1950) or by POFI, and useful to look for evidence that different methf measurement may have been used. Godsil's ple from Panama and Costa Rica came from rea close to that of Schaefer and Walford's Costa Rica, and agreement among the four acters available for comparison is generally even though Godsil's fish have slightly longer s and a slightly longer distance from the snout rst dorsal fin. In addition, Godsil's sample Hawaii may be compared with that of POFI, was obtained from rather limited areas: the l fish came from near Johnston Island and off ds between Kauai and French Frigate Shoals the large fish from the Honolulu fish market. POFI sample was obtained from a much r area, although again most of the large fish measured in the Honolulu market. Five urements in two size groups are available to pare, and in not a single instance is the differbetween means great enough to separate the x bars (and indicate a statistically significant rence).

ot as close statistically are Godsil and Green- 's samples from Palmyra Island and the I samples from the eastern and western Line ds, but the differences are complicated. ples are available for comparison of small and um size yellowfin taken by Godsil and Green- with similar sizes taken by POFI from the ern Line Islands and a sample of medium size wfin from the eastern Line Islands. Godsil Greenhood's data from Palmyra Island were ined from frozen fish in a catch made during t 12 days of fishing in the vicinity of Fanning Palmyra Islands. These days were nearly ecutive during February 1949. The POFI les of small and medium fish were obtained these islands as well as in the vicinity of the nboring Washington and Christmas Islands, man Reef, and a few from farther offshore. (All of these islands are near the borderline between our eastern and western Line Islands areas.) They were, however, taken over a much longer period (table 2) so they should be much more representative of the areas than Godsil and Greenhood's samples.

When a comparison of the mean character sizes of group M fish is made between our eastern and western Line Islands samples, not a single character differs by more than the length of the black bars, except height of the anal fin, and here the difference is in line with the general trend along the Equator. But when these two samples and the sample of small yellowfin from the western Line Islands are compared with Godsil and Greenhood's sample, I find that in head length their group M runs smaller and their group S somewhat larger; in distance from snout to insertion of first dorsal fin, their group M is about the same, and their group S considerably larger. Their distances from snout to insertions of second dorsal and anal fins show fairly good agreement with POFI samples. In the last character—distance from snout to insertion of the ventral fins—there is fairly good agreement between Godsil and Greenhood's sample and the POFI sample from the western Line Islands for group S; but then for group M the distance is markedly shorter than in either of the other two samples. Such erratic results suggest either that Godsil and Greenhood may have been sampling too few schools of fish to obtain a thoroughly representative sample or that freezing and thawing may have changed the proportions of the fish.

Despite these differences, I conclude that the techniques of measurement used by POFI were sufficiently close to those used by Godsil and Greenhood to arrive at about the same conclusions with regard to morphological differences among yellowfin from different areas of the Pacific.

MULTIPLE CHARACTER COMPARISON

After having examined the data for the mean differences in body shape, I shall consider next the overlap of the frequency distributions not merely of one character but of all characters considered simultaneously.

The measure of overlap that I shall use is similar to the measures of overlap used by taxonomists in many fields (Mayr et al., 1953: 146). The measures have all arisen from the concept of

two overlapping frequency distributions and are expressed either as the percent of the actual frequency classes in the area of overlap or as a proportion of the observations estimated to be in the area of overlap of two normal distributions. The amount of overlap can be indicated as the distance between the means in units of the standard deviation or as an area under the curves. I prefer a measure of the overlapping area under two normal curves, which I have described fully (Royce, 1957) and which I have called Ω. The overlap (Ω) is expressed as a percent and varies from 0 to 100 as the means of the distributions approach one another.

This concept of overlap is especially useful because it answers the question, "What parts of population *A* possess characters that are within the range of population *B*?" I shall construe the answer to this question as a maximum for the proportion of population *A* which might have migrated from the area of population *B*.

In the computational procedure I shall follow closely the method outlined by Rao (1952, chapters 8 and 9). His method starts with pooled estimates of the correlations and standard deviations which are applied to the normalized mean values in order to transform them to values that are uncorrelated and that have unit standard deviations. In this method of analysis the amount of work increases approximately as the square of the number of characters used. To reduce the number, we have dropped from further consideration the greatest body depth, the distance from insertion of ventral fin to anterior edge of vent, and the distance from snout to insertion of ventral fins. This procedure seemed justifiable because (1) in some of our samples one or more of these characters were not measured, (2) none of them revealed as large differences between areas as other characters, (3) the distance from snout to insertion of ventral fins is highly correlated with head length and distance from snout to insertion of anal fin, and (4) it will be shown subsequently that seven characters are probably more than are necessary.

Because the statistics have arisen from regression analysis, it will be necessary to substitute for Rao's statistics comparable statistics determined from regression. Instead of the intragroup standard deviations from the mean, I use the intragroup standard deviations from regression. Instead of the intragroup correlation the several characters, I use the intrag partial correlations independent of total le Instead of the actual mean values of the ch ters, I use the mean values estimated for ce given fork lengths. Therefore, in all of the st tics the effect of any changes with fork le is removed.

It has been impossible to assume that th gression lines were satisfactory beyond lin length groups, so we have broken down all o statistics (except for partial correlations) int length groups which were used in the pre section for character-by-character compari They are group S, composed of fish less 80-cm. fork length, which are compared length of 65 cm. (about 12 lb.); group M, 80 to 120 cm., compared at a length of 100 (43 lb.); and group L, more than 120 cm., pared at a length of 140 cm. (118 lb.). The regression constants, means, et cetera are in appendix.

Because adequacy of the sampling v widely, I have sought to obtain estimate standard deviations from samples that I con to be more representative. I have chosen three areas most widely represented in time among all three length groups; namely, Ha western Line Islands, and eastern Car Islands. From these samples for each char in each size group I have obtained the stan deviation from regressions squared, $S_{y.x^2}$, aver it for the three areas, and ended with an esti of a pooled standard deviation from regre (within groups) which gives equal weight t three areas (table 5).

TABLE 5.—*Pooled mean standard deviations from regr for each body character for the three size group*

Size group (cm.)	Head length	Length of pectoral fin	Height of—		Snout to inserti	
			Second dorsal fin	Anal fin	First dorsal fin	Second dorsal fin
Small, <80	0.3981	0.7822	0.03163	0.03283	0.4470	0.5990
Medium, 80–120	.5903	1.2891	.04626	.06141	.6776	.9426
Large, >120	.6596	1.2280	.06011	.05680	.7576	.9581

These standard deviations are the basic of morphological distance, and it is desirab examine them to determine how represent they are of all samples. Two matters are nent: first, I have used the actual stan

tion from regression without adjusting for ifference of the mean $\bar{x}$ from the X used for arisons, so I need to know how close the s are to the comparison values; and second d to consider whether the average dispersion the lines is close to the grand average of all les. The mean lengths of the three areas ıg equal weight to each) are 62.10, 99.32, 142.04 cm. The means chosen for comon are 65, 100, and 140 cm. If we consider the standard deviation is directly proporl to the length of fish, then I have tended to restimate slightly the standard deviation ıe small and the medium groups and have ly overestimated it for the large group.

addition, the standard deviation of $\hat{Y}$ ines with distance from $\bar{y}$. For this reason re tended to slightly underestimate the $S_{y.x}$ ıe small and large groups.

ıally, the average coefficients of variation 4) of the three selected areas (for five cters) for the three size groups are 1.85, 1.80, 1.63. These coefficients are close to the l means of all samples, which are 1.74, 1.81, 1.81 for small, medium, and large groups, ctively. With these partly compensating n all cases small differences, I have chosen ake no adjustments but used the standard tions from regression directly with confidence they are very close to the grand average.

r the partial correlations of the several ıcters independent of fork length I have used ected sample of 30 fish each from Hawaii, ı Rica, eastern Line Islands, western Line ds, and central Carolines. The 30 fish were ed from each area in the size range from 80 0 cm. and were chosen at random within the group. From these, the intragroup correla- (table 6) and partial correlations were lated (table 7).[7]

ɔm the means and the pooled standard ıtions the normalized mean values of each ıcter have been obtained. The means were ly averaged to obtain a grand average, and the deviations of each mean from the grand average in units of the average standard deviation were found (table 8).

Using the notation of Rao (1952), the normalized mean values $x_1 \ldots x_p$ were then transformed to values $Y_1 \ldots Y_p$, which are uncorrelated, and subsequently to other values $y_1 \ldots y_p$, which have unit standard deviation. The general formulas as given by Rao are—

$$Y_p = x_p - a_{pp-1} - \ldots - a_{p1} Y_1$$

$$a_{ij} = \frac{b_{ij}}{V(Y_j)} \text{ when } j < i-1$$

$$b_{ij} = \lambda_{ij} - \sum_{t=j-1}^{1} a_{jt} b_{it}$$

$$V(Y_i) = \lambda_{ii} - \sum_{j=1}^{i-1} a_{ij} b_{ij}$$

$$y_i = \frac{Y_i}{\sqrt{V(Y_i)}}.$$

The a and b values (tables 9 and 10) are convenient intermediate values in the computations. $V(Y_i)$ (table 11) is the variance of Y_i and y_i and is the final transformed value of the normalized mean (table 12). From these transformed means which have unit standard deviation and which are uncorrelated with one another, I obtained the distance in units of the standard deviation squared (D^2) for each possible area comparison in each size group (table 13). The total D^2, obtained by adding the D^2 values for each of the seven characters, is subject to a small bias due to the number of characters and the size of the samples. This bias (which is largest in the smallest samples and most troublesome in the samples most closely related) is removed by subtracting the value

$$p\frac{n_1+n_2}{n_1 n_2},$$

in which p is the number of characters and n_1 and n_2 the number of observations in each sample (Rao, 1952: 364).[8]

From the adjusted sum of D^2 the value of the overlap (Ω) is determined by finding D, then $\frac{D}{2}$, which is used as an argument to enter the tables of the area under a normal curve to find the area of one tail and then multiplying by 200 to express the area of two tails as a percentage Ω.

[7] table of partial correlations is one of the more laborious parts of the computation. The particular data were chosen during preliminary ations as a test of the method on rather widely dispersed groups, all ood sample coverage. The size group corresponds nearly but not to size group M. I have assumed that the partial correlations of ody parts for what is essentially the medium-size group for five with wide coverage are the same for all areas and also for the small ge size groups.

[8] I have ignored the slight variation in value of n among different characters within the samples.

TABLE 6.—*Intragroup correlations of body characters*

[See text for explanations]

Character	Head length	Length of pectoral fin	Height of—		Snout to insertion of—		
			Second dorsal fin	Anal fin	First dorsal fin	Second dorsal fin	An
Fork length	0.98422	0.92124	0.93830	0.92534	0.97846	0.99448	
Head length		.90009	.92767	.91515	.98329	.98667	
Length of pectoral fin			.92373	.89801	.89439	.90894	
Height of—							
Second dorsal fin				.96177	.91393	.92877	
Anal fin					.90770	.91479	
Snout to insertion of—							
First dorsal fin						.98647	
Second dorsal fin							

TABLE 7.—*Partial correlations of body characters, independent of fork length*

Character	Head length	Length of pectoral fin	Height of—		Snout to insertion of—		An
			Second dorsal fin	Anal fin	First dorsal fin	Second dorsal fin	
Head length	1.0000	−0.0960	0.0683	0.0657	0.5549	0.4243	
Length of pectoral fin		1.0000	.4409	.3088	−.0873	−.1766	
Height of—							
Second dorsal fin			1.0000	.7133	−.0583	−.1199	
Anal fin				1.0000	.0292	−.1367	
Snout to insertion of—							
First dorsal fin					1.0000	.6191	
Second dorsal fin						1.0000	
Anal fin							

TABLE 8.—*Normalized mean values* x_i *of body characters*

Size group and area	Head length	Length of pectoral fin	Height of—		Snout to insertion of—		A
			Second dorsal fin	Anal fin	First dorsal fin	Second dorsal fin	
SMALL-SIZE GROUP							
West Line Islands	0.9797	−0.3068	−0.2308	−0.1889	−0.2461	0.0334	
Phoenix Islands	.6782	−.0511	.5185	.2315	−.2237	−.0334	
Bikini Island	−.5024	.2813	−.2940	−.1614	.9843	−.4841	
East Caroline Islands	−.5777	1.3424	1.2235	1.2489	−.7383	−.5175	
Central Caroline Islands	−.7284	1.5597	1.3468	1.0448	−.7383	−.4674	
Japan	−.3266	.3963	.3351	.1340	−.2013	.1669	
Hawaii	−.5526	−.1790	−.1676	−.0061	.3803	.5342	
Northeast Africa	1.1304	−3.0043	−2.7347	−2.3089	.8725	.7846	
MEDIUM-SIZE GROUP							
Costa Rica	.8809	−1.4274	−1.7034	−1.3109	.4870	1.0397	
East Line Islands	.6776	−.5740	−.2810	−.3843	−.0443	−.2228	
West Line Islands	.5590	−.1164	.0843	.2215	0	−.2228	
Phoenix Islands	.1016	.7214	.5275	.6009	−.1033	−.5092	
East Caroline Islands	−1.2197	.9619	1.1911	1.0780	−.5313	−.7532	
Central Caroline Islands	−1.2367	1.2411	1.1176	.9168	−.5756	−.8805	
Hawaii	−.5252	−.1551	−.4172	−.3713	.3542	.3395	
Angola, Africa	.7623	−.6283	−.5275	.7572	.4280	1.2306	
LARGE-SIZE GROUP							
109°–119° W	.2122	−1.3029	−1.5339	−1.9894	.1320	1.2420	
119°–129° W	.3335	−.5130	−1.1429	−1.2993	.5280	.4175	
129°–139° W	.2426	−.5782	−.8285	−.8838	.4884	.5219	
139°–149° W	.0910	.2524	−.5107	−.4806	−.0528	.1774	
East Line Islands	−.2122	.1629	.2196	.2289	−.2640	−.1566	
West Line Islands	.3487	.3502	.5523	.6954	−.5412	−.3862	
Phoenix Islands	−.2122	.3339	.7969	1.0000	−.4488	−.3549	
East Marshall Islands	−.5761	.2769	1.2610	1.4754	−.1584	−.0417	
East Caroline Islands	−.6216	.5375	1.3026	1.5933	−.2376	−1.0437	
Central Caroline Islands	−.2274	.4805	1.3159	1.5827	−.3300	−.9498	
Hawaii	−.6822	.3013	−.3876	−.4947	.1188	−.2818	
Angola, Africa	1.3190	−.2606	−1.0497	−1.4261	.8316	.9185	

The results of these computations expressed as the percentage of overlap between areas appear in table 14. Here the equatorial series has been arranged in order from Costa Rica on the east to the central Carolines on the west. The s samples from Bikini Island, Japan, Ha Angola, and northeast Africa are added i special order.

TABLE 9.—*Table of* a

[See text for explanation]

Character	Head length	Length of pectoral fin	Height of—		Snout to insertion of—		
			Second dorsal fin	Anal fin	First dorsal fin	Second dorsal fin	Anal fin
ngth	1.0000	−0.0960	0.0633	0.6507	0.5549	0.4243	0.4387
of pectoral fin		1.0000	.45162	.31804	−.03435	−.13713	−.06731
of—							
ond dorsal fin			1.0000	.71415	−.10190	−.11033	−.14654
l fin				1.0000	.12486	−.11991	−.21979
o insertion of—							
t dorsal fin					1.0000	.55912	.01926
ond dorsal fin						1.0000	.14781
l fin							1.0000

TABLE 10.—*Table of* b

[See text for explanation]

Character	Head length	Length of pectoral fin	Height of—		Snout to insertion of—		
			Second dorsal fin	Anal fin	First dorsal fin	Second dorsal fin	Anal fin
ngth	1.0000	−0.0960	0.0683	0.0657	0.5549	0.4243	0.4387
of pectoral fin		1.0000	.44746	.31511	−.03403	−.13587	−.06668
of—							
ond dorsal fin			1.0000	.56650	−.08083	−.08752	−.11625
l fin				1.0000	−.06129	−.05886	−.10790
o insertion of—							
st dorsal fin					1.0000	.37742	.01300
ond dorsal fin						1.0000	.08478
l fin							1.0000

RE.—These values are recorded in 5 significant figures; however, 8 significant figures were carried in the computations leading to *a*-values. The first s obtained by preceding computations to 4 significant figures.

E 11.—*Variances and square roots of variances for various body measurements*

[See text for explanation]

te	Variance [1] $V(Y_i)$	D $\sqrt{V(Y_i)}$	Variate	Variance [1] $V(Y_i)$	D $\sqrt{V(Y_i)}$
	1.00000	1.00000	$V(Y_6)$	.57360	.75736
	.99078	.99538	$V(Y_7)$	.74952	.86575
	.79325	.89065	$V(Y_8)$	.76599	.87521
	.49090	.70064	$V(Y_9)$	.40215	.63415
	.67503	.82160	$V(Y_{10})$	.33024	.57466

ues are recorded in 5 significant figures; however, 8 significant figures rried in the computations leading to *a*-values (in table 9).

the equatorial series there is a clear tendency nore closely located samples to have greater ap. The overlap varies from a maximum of ercent and 81 percent in medium and large groups for the comparison between eastern lines and central Carolines to a low of 3 ent for the comparison of Costa Rica with rn Carolines and central Carolines. The ion of the average overlap to the separation e samples in miles (fig. 19) is clear cut and the same in all size groups. This graph been made with the assumption that each lation was located in the center of each 10° of longitude and that the centers of these ns were separated by units of 600 miles.

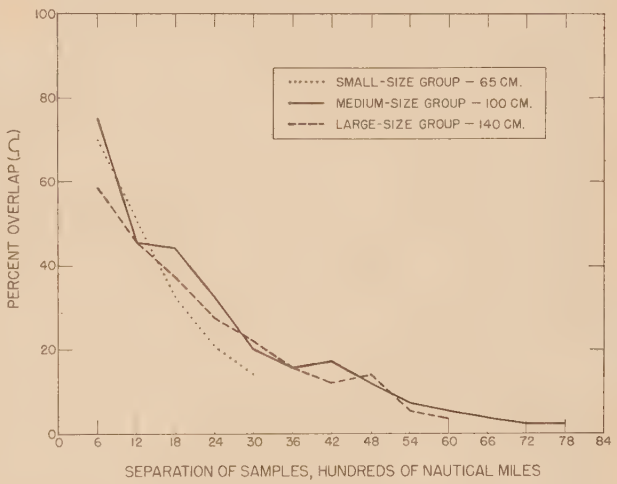


FIGURE 19.—Average percent of overlap of samples of yellowfin from the equatorial Pacific.

(This assumption disregards the small variations in location within the sample areas and the fact that one sample area was 11° of longitude in width instead of 10°.)

From this graph it appears that, on the average, samples of yellowfin tuna from along the Equator separated by 1,500 miles overlap less than 50

TABLE 12.—*Transformed normalized mean values* y_i *of characters*

[See text for explanation]

Size group and area	Head length	Length of pectoral fin	Height of—		Snout to insertion o	
			Second dorsal fin	Anal fin	First dorsal fin	Second dorsal fin
SMALL-SIZE GROUP						
West Line Islands	0.9797	−0.2137	−0.2209	−0.0644	−0.9877	0.0200
Phoenix Islands	.6782	.0141	.5269	−.2178	−.6483	.0159
Bikini Island	−.5024	.2342	−.4126	.0855	1.4924	−1.2648
East Caroline Islands	−.5777	1.2929	.7622	.5606	−.4301	.2953
Central Caroline Islands	−.7284	1.4967	.8085	.1493	−.2710	.3465
Japan	−.3266	.3666	.2144	−.1384	.0293	.5073
Hawaii	−.5526	−.2331	−1.0979	.2481	.7879	.5083
Northeast Africa	1.1304	−2.9092	−1.6824	−.5596	.5116	−.4330
MEDIUM-SIZE GROUP						
Costa Rica	.8809	−1.3491	−1.2942	−.1691	−.1833	.5606
East Line Islands	.6776	−.5113	−.1056	−.2852	−.5141	−.4994
West Line Islands	.5590	−.0630	.0867	.2135	−.3933	−.3452
Phoenix Islands	.1016	.7346	.2143	.3217	−.1744	−.4276
East Caroline Islands	−1.2197	.8487	.9957	.3656	.2835	−.1604
Central Caroline Islands	−1.2367	1.1276	.7736	.2127	.2444	−.2908
Hawaii	−.5252	−.2065	−.3269	−.0907	.7508	.1975
Angola, Africa	.7623	−.5577	−.3650	−.5689	.0031	.9849
LARGE-SIZE GROUP						
109°–119° W	.2122	−1.2885	−1.0870	−1.2903	−.0190	1.0161
119°–129° W	.3335	−.4832	−1.0630	−.7023	.3547	−.1536
129°–139° W	.2426	−.5575	−.6661	−.4276	.3794	.0888
139°–149° W	.0910	.2448	−.7034	−.1665	−.1755	.2241
East Line Islands	−.2122	.1432	.1894	.1100	−.1628	.0735
West Line Islands	.3487	.3855	.4008	.4218	−.8788	−.0040
Phoenix Islands	−.2122	.3150	.7508	.6232	−.3732	.1000
East Marshall Islands	−.5761	.2226	1.3444	.8387	.2648	.4147
East Caroline Islands	−.6216	.4800	1.2644	.9676	.1873	−.7855
Central Caroline Islands	−.2274	.4608	1.2610	.9273	−.1883	−.6629
Hawaii	−.6822	.2369	−.5063	−.2895	.5901	−.4029
Angola, Africa	1.3190	−.1346	−1.2044	−1.0049	.0897	.1274

percent in the seven characters considered; those separated by 3,000 miles overlap less than 25 percent; and those separated by 6,000 miles overlap less than 6 percent.

The graph also shows that the average overlap varies little with the size group of fish, although the data in table 14 indicate a slight tendency for the small and medium size groups to have less overlap than the large. This tendency appears to be most marked in the comparisons of samples from the western Line and Phoenix Islands areas with those from the eastern and central Caroline Islands areas. In all of these comparisons the large size group shows the most overlap and the small size group the least. In the comparisons of the Hawaiian samples with those from the equatorial area, the small size group shows the least overlap, but the medium size group generally shows slightly greater overlap than the large. The data are too scant to establish the significance of this tendency, but it may be associated with more wandering by the larger fish.

The overlap of the other samples with those from the equatorial Pacific area follows, in general, the relations that were deduced from consideration of single characters. The Bikini Island sample shows rather little overlap with any equatorial samples—even the sample from nearby Caroline Islands area—but a conside overlap with samples from Japan and Ha The Japanese sample, on the other han apparently intermediate in structure betwee Bikini Island and equatorial samples, for it a considerable overlap with all other samples a comparison is possible. The samples Hawaii, likewise, show a fairly large amou overlap with most of the equatorial samples the largest size group is most similar t equatorial yellowfin from between longitudes and 159° W. This area is generally southe Hawaii rather than directly south. The Ar Africa, fish show a large amount of overlap the large fish from longitudes 119° to 149 They are as similar to these fish as are ma the samples from adjoining areas along Pacific Equator. Moreover, in all compar of Angola samples with samples from 11 149° W. there is a marked tendency for the ov to be less among the larger size group tha medium size group. This finding conforms the observation made by Schaefer and Wa (1950) that the principal characters differenti

13.—*Value of D^2 computed from transformed means and adjusted for sample size to determine percentage of overlap* (Ω)

Size group and area	Head length	Length of pectoral fin	Height of—		Snout to insertion of—			D^2	Bias	Adjusted D^2	Ω
			Second dorsal fin	Anal fin	First dorsal fin	Second dorsal fin	Anal fin				
SMALL-SIZE GROUP											
ıe-Phoenix Islands	0.0909	0.0519	0.5592	0.0235	0.1152	0.0000+	0.0484	0.8891	0.3482	0.5409	71
-Bikini Island	2.1966	.2006	.0367	.0225	6.1509	1.6507	.1266	10.3846	.3849	9.9997	11
-East Caroline Islands	2.4255	2.2698	.9665	.3906	.3109	.0758	.0566	6.4957	.2758	6.2199	21
-Central Caroline Islands	2.9176	2.9255	1.0597	.0457	.5137	.1066	1.0772	8.6460	.3482	8.2978	15
-Japan	1.7064	.3367	.1895	.0055	1.0343	.2375	.2515	3.7614	.3849	3.3765	36
-Hawaii	2.3479	.0004	.7691	.0977	3.1528	.2384	1.3988	8.0051	.3535	7.6516	17
-Northeast Africa	.0227	7.2657	2.1360	.2452	2.2479	.2052	5.2276	17.3503	.3049	17.0454	4
Bikini Islands	1.3938	.0484	.8827	.0920	4.5826	1.6402	.3314	8.9711	.4150	8.5561	14
East Caroline Islands	1.5773	1.6353	.0554	.6059	.0476	.0781	.2096	4.2092	.3059	3.9033	32
Central Caroline Islands	1.9785	2.1981	.0793	.1348	.1424	.1093	1.5821	6.2245	.3784	5.8461	23
Japan	1.0096	.1243	.0977	.0063	.4591	.2415	.5204	2.4589	.4150	2.0439	47
Hawaii	1.5149	.0611	2.6400	.2171	2.0627	.2748	1.9673	8.7379	.3836	8.3543	15
Northeast Africa	.2045	8.5457	4.8810	.1168	1.3454	.2015	6.2815	21.5764	.3350	21.2414	2
ast Caroline Islands	.0057	1.1208	1.3802	.2257	3.6960	2.4339	.0139	8.8762	.3425	8.5337	14
entral Caroline Islands	.0511	1.5939	1.4911	.0041	3.1096	2.5963	.4653	9.3114	.4150	8.8964	14
apan	.0309	.0175	.3931	.0501	2.1407	3.1403	.0212	5.7938	.4516	5.3422	25
lawaii	.0025	.2184	.4696	.0264	.4963	3.1439	.6838	5.0409	.4203	4.6206	28
ortheast Africa	2.6660	9.8810	1.6124	.4162	.9620	.6919	3.7272	19.9567	.3716	19.5851	3
roline-Central Caroline Islands	.0227	.0415	.0021	.1692	.0253	.0026	.6400	.9034	.3059	.5975	70
-Japan	.0631	.8580	.3001	.4886	.2110	.0449	.0695	2.0352	.3425	1.6927	51
-Hawaii	.0006	2.3287	3.4600	.0977	1.4835	.0454	.8926	8.3085	.3111	7.9974	16
-Northeast Africa	2.9176	17.6576	5.9761	1.2548	.8868	.5304	4.1964	33.4197	.2625	33.1572	.4
Caroline Islands-Japan	.1614	1.2771	.3530	.0828	.0902	.0259	.2877	2.2781	.4150	1.8631	49
-Hawaii	.0309	2.9922	3.6344	.0098	1.1213	.0262	.0210	7.8358	.3836	7.4522	17
-Northeast Africa	3.4551	19.4120	6.2046	.5025	.6125	.6076	1.5588	32.3531	.3350	32.0181	.4
awaii	.0511	.3596	1.7221	.1494	.5755	.0000+	.4640	3.3217	.4203	2.9014	39
ortheast Africa	2.1228	10.7309	3.5979	.1774	.2326	.8842	3.1859	20.9317	.3716	20.5601	2
Northeast Africa	2.8325	7.1615	.3416	.6524	.0763	.8860	1.2182	13.1685	.3403	12.8282	7
D^2	33.8002	101.3132	45.2911	6.3107	37.8848	20.1191	36.5245				
ean	1.2072	3.6183	1.6175	.2254	1.3530	.7185	1.3044				
neans	1.2072	4.8255	6.4430	6.6684	8.0214	8.7399	10.0443				
	58	27	20	20	16	14	11				
MEDIUM-SIZE GROUP											
ica-East Line Islands	0.0413	0.7019	1.4128	0.0135	0.1094	1.1236	4.3052	7.7077	0.4535	7.2542	18
-West Line Islands	.1036	1.6541	1.9069	.1464	.0441	.8205	4.7594	9.4350	.3218	9.1132	13
-Phoenix Islands	.6073	4.3418	2.2756	.2409	.0001	.9765	4.7476	13.1898	.3600	12.8298	7
-East Caroline Islands	4.4125	4.8303	5.2436	.2859	.2179	.5198	4.4741	19.9841	.3686	19.6155	3
-Central Caroline Islands	4.4842	6.1340	4.2758	.1458	.1829	.7249	2.6387	18.5863	.3100	18.2763	3
-Hawaii	1.9771	1.3055	.9357	.0061	.8725	.1318	.9461	6.1748	.4473	5.7275	23
-Angola, Africa	.0141	.6263	.8634	.1598	.0347	.1800	.9580	2.8363	.5747	2.2616	45
ıe-West Line Islands	.0141	.2010	.0370	.2487	.0146	.0238	.0114	.5506	.2926	.2580	80
-Phoenix Islands	.3318	1.5523	.1023	.3683	.1154	.0052	.0108	2.4861	.3308	2.1553	46
-East Caroline Islands	3.5997	1.8496	1.2129	.4235	.6362	.1149	.0016	7.8384	.3394	7.4990	17
-Central Caroline Islands	3.6645	2.6860	.7730	.2479	.5753	.0435	.2030	8.1932	.2807	7.9125	16
-Hawaii	1.4467	.0929	.0490	.0378	1.6000	.4857	1.2148	4.9269	.4180	4.5089	19
-Angola, Africa	.0072	.0022	.0673	.0805	.2675	2.2031	1.2014	3.8292	.5454	3.2838	36
ne-Phoenix Islands	.2092	.6362	.0163	.0117	.0479	.0068	.0000+	.9281	.1991	.7290	67
-East Caroline Islands	3.1638	.8312	.8263	.0231	.4581	.0342	.0044	5.3411	.2077	5.1334	26
-Central Caroline Islands	3.2245	1.4175	.4718	.0000+	.4067	.0030	.3105	5.8340	.1491	5.6849	23
-Hawaii	1.1755	.0206	.1711	.0925	1.3090	.2945	1.4614	4.5246	.2863	4.2383	30
-Angola, Africa	.0413	.2447	.2040	.6121	.1571	1.7692	1.4467	4.4751	.4138	4.0613	31
-East Caroline Islands	1.7458	.0130	.6106	.0019	.2097	.0714	.0041	2.6565	.2459	2.4106	44
-Central Caroline Islands	1.7910	.1544	.3128	.0119	.1754	.0187	.3075	2.7717	.1873	2.5844	42
-Hawaii	.3929	.8857	.2929	.1701	.8560	.3908	1.4549	4.4433	.3245	4.1188	31
-Angola, Africa	.4365	1.6700	.3356	.7932	.0315	1.9952	1.4402	6.7022	.4520	6.2502	21
roline-Central Caroline Islands	.0003	.0778	.0493	.0234	.0015	.0170	.2409	.4102	.1959	.2143	82
-Hawaii	.4823	1.1134	1.7493	.2082	.2184	.1281	1.3053	5.2050	.3332	4.8718	27
-Angola, Africa	3.9283	1.9780	1.8515	.8733	.0786	1.3117	1.2914	11.3128	.4606	10.8522	10
Caroline Islands-Hawaii	.5062	1.7798	1.2111	.0921	.2564	.2384	.4247	4.5087	.2745	4.2342	30
-Angola, Africa	3.9960	2.8402	1.2964	.6109	.0582	1.6274	.4168	10.8459	.4019	10.4440	11
-Angola, Africa	1.6577	.1233	.0015	.2287	.5591	.6200	.0000+	3.1903	.5392	2.6511	41
D^2	43.4554	39.7637	28.5558	6.1582	9.4942	15.8797	35.5809				
lean	1.5520	1.4201	1.0199	.2199	.3391	.5671	1.2707				
neans	1.5520	2.9721	3.9920	4.2119	4.5510	5.1181	6.3888				
	53	39	32	30	29	26	21				
LARGE-SIZE GROUP											
° West-119°–129° W	.0147	.6485	.0006	.3457	.1397	1.3682	1.6871	4.2045	.4823	3.7222	33
-129°–139° W	.0009	.5344	.1772	.7443	.1587	.8599	.3214	2.7968	.4823	2.3145	45
-139°–149° W	.1469	2.3510	.1471	1.2629	.0245	.6273	.4185	4.9782	.3953	4.5829	28
-East Line Islands	.1801	2.0498	1.6292	1.9608	.0207	.8885	.0039	6.7330	.3779	6.3551	21
-West Line Islands	.0186	2.8023	2.2135	2.9313	.7393	1.0406	.7218	10.4674	.4540	10.0134	11
-Phoenix Islands	.1801	2.5712	3.3775	3.6615	.1255	.8392	1.3870	12.1420	.4855	11.6565	9
-East Marshall Islands	.6214	2.2834	5.9117	4.5326	.0805	.3617	.7691	14.5604	.5083	14.0521	6
-East Caroline Islands	.6952	3.1276	5.5291	5.0981	.0426	3.2458	2.0261	19.7645	.4583	19.3062	3
-Central Caroline Islands	.1932	3.0601	5.5131	4.9177	.0287	2.8190	1.1591	17.6909	.4306	17.2603	4
-Hawaii	.8000	2.3268	.3372	1.0016	.3710	2.0136	.0580	6.9082	.3860	6.5222	20
-Angola, Africa	1.2250	1.3315	.0138	.0815	.0118	.7898	1.2522	4.7056	.5926	4.1130	31

TABLE 13.—*Value of D^2 computed from transformed means and adjusted for sample size to determine percentage of overlap*
Continued

Size group and area	Head length	Length of pectoral fin	Height of—		Snout to insertion of—			D^2	Bias	Adjusted D^2
			Second dorsal fin	Anal fin	First dorsal fin	Second dorsal fin	Anal fin			
LARGE-SIZE GROUP—continued										
119°–129° West-129°–139° W	0.0083	0.0055	0.1575	0.0755	0.0006	0.0588	0.5358	0.8420	0.2979	0.544
-139°–149° W	.0588	.5300	.1293	.2871	.2811	.1427	.4251	1.8541	.2109	1.643
-East Line Islands	.2978	.3924	1.5685	.6598	.2678	.0516	1.8531	5.0910	.1935	4.897
-West Line Islands	.0002	.7546	2.1427	1.2636	1.5215	.0224	.2019	5.9069	.2696	5.637
-Phoenix Islands	.2978	.6371	3.2899	1.7570	.5298	.0643	.0147	6.5906	.3011	6.289
-East Marshall Islands	.8274	.4982	5.7956	2.3747	.0081	.3230	.1780	10.0050	.3239	9.681
-East Caroline Islands	.9122	.9278	5.4168	2.7886	.0280	.3993	.0155	10.4882	.2739	10.214
-Central Caroline Islands	.3146	.8911	5.4010	2.6556	.2948	.2594	.0494	9.8659	.2462	9.619
-Hawaii	1.0316	.5185	.3099	.1704	.0554	.0622	1.1194	3.2674	.2016	3.065
-Angola, Africa	.9712	.1215	.0200	.0916	.0702	.0790	.0324	1.3859	.4082	.977
129°–139° West-139°–149° W	.0230	.6437	.0014	.0682	.3079	.0183	.0064	1.0689	.2109	.858
-East Line Islands	.2068	.4910	.7319	.2890	.2940	.0002	.3960	2.4089	.1935	2.215
-West Line Islands	.0113	.8892	1.1383	.7215	1.5831	.0086	.0799	4.4319	.2696	4.162
-Phoenix Islands	.2068	.7613	2.0076	1.1042	.5664	.0001	.3731	5.0195	.3011	4.718
-East Marshall Islands	.6703	.6086	4.0421	1.6035	.0131	.1062	.0962	7.1400	.3239	6.816
-East Caroline Islands	.7468	1.0764	3.7268	1.9466	.0369	.7644	.7336	9.0315	.2739	8.757
-Central Caroline Islands	.2209	1.0369	3.7137	1.8358	.3223	.5651	.2598	7.9545	.2462	7.708
-Hawaii	.8553	.6311	.0255	.0191	.0444	.2418	.1063	1.9235	.2016	1.721
-Angola, Africa	1.1586	.1788	.2898	.3333	.0839	.0015	.3048	2.3507	.4082	1.942
139°–149° West-East Line Islands	.0919	.0103	.7971	.0765	.0002	.0227	.5031	1.5018	.1065	1.395
-West Line Islands	.0664	.0198	1.2193	.3461	.4946	.0520	.0411	2.2393	.1826	2.056
-Phoenix Islands	.0919	.0049	2.1147	.6236	.0391	.0154	.2817	3.1713	.2141	2.957
-East Marshall Islands	.4450	.0005	4.1935	1.0104	.1939	.0363	.0529	5.9325	.2369	5.695
-East Caroline Islands	.5078	.0553	3.8722	1.2861	.1316	1.0193	.6030	7.4753	.1869	7.288
-Central Caroline Islands	.1014	.0467	3.8589	1.1964	.0002	.7868	.1846	6.1750	.1592	6.015
-Hawaii	.5978	.0001	.0388	.0151	.5861	.3931	.1648	1.7958	.1146	1.681
-Angola, Africa	1.5080	.1439	.2510	.7029	.0703	.0094	.2229	2.9084	.3212	2.587
East Line-West Line Islands	.3146	.0587	.0447	.0972	.5127	.0060	.8317	1.8656	.1653	1.700
-Phoenix Islands	.0000+	.0295	.3152	.2634	.0443	.0007	1.5378	2.1909	.1967	1.994
-East Marshall Islands	.1324	.0063	1.3340	.5310	.1828	.1164	.8825	3.1854	.2196	2.965
-East Caroline Islands	.1676	.1135	1.1556	.7355	.1226	.7379	2.2076	5.2403	.1696	5.070
-Central Caroline Islands	.0002	.1009	1.1483	.6670	.0007	.5423	1.2973	3.7567	.1418	3.614
-Hawaii	.2209	.0088	.4840	.1596	.5669	.2270	.0920	1.7592	.0972	1.662
-Angola, Africa	2.3446	.0772	1.9427	1.2430	.0638	.0029	1.3957	7.0699	.3038	6.766
West Line-Phoenix Islands	.3146	.0050	.1225	.0406	.2556	.0108	.1076	.8567	.2729	.583
-East Marshall Islands	.8553	.0265	.8904	.1738	1.3078	.1753	.0751	3.5042	.2957	3.208
-East Caroline Islands	.9415	.0889	.7458	.2979	1.1366	.6107	.3292	4.0706	.2457	3.824
-Central Caroline Islands	.3319	.0057	.7399	.2555	.4768	.4341	.0515	2.2954	.2179	2.077
-Hawaii	1.0628	.0221	.8228	.5059	2.1577	.1591	.3705	5.1009	.2476	4.853
-Angola, Africa	.9415	.2705	2.5767	2.0355	.9380	.0173	.0726	6.8521	.3799	6.472
Phoenix-East Marshall Islands	.1324	.0085	.3524	.0464	.4070	.0996	.0904	1.1361	.3272	.808
-East Caroline Islands	.1676	.0272	.2638	.1186	.3142	.7841	.0604	1.7359	.2772	1.458
-Central Caroline Islands	.0002	.0213	.2603	.0925	.0342	.5826	.6546	1.6451	.2494	1.395
-Hawaii	.2209	.0061	1.5803	.8330	.9279	.2529	.8776	4.6987	.2048	4.493
-Angola, Africa	2.3446	.2021	3.8228	2.6507	.2143	.0008	.0034	9.2387	.4114	8.827
East Marshall-East Caroline Islands	.0021	.0663	.0064	.0166	.0060	1.4405	.2986	1.8365	.3000	1.536
-Central Caroline Islands	.1216	.0567	.0070	.0078	.2053	1.1612	.0398	1.5994	.2722	1.327
-Hawaii	.0113	.0002	3.4251	1.2728	.1058	.6685	.4046	5.8883	.2276	5.660
-Angola, Africa	3.5914	.1276	6.4964	3.3989	.0307	.0825	.0586	13.7861	.4343	13.351
East Caroline-Central Caroline Islands	.1554	.0004	.0000+	.0016	.1411	.0150	.1203	.4338	.2222	.211
-Hawaii	.0037	.0591	3.1354	1.5803	.1622	.1464	1.3983	6.4854	.1776	6.307
-Angola, Africa	3.7659	.3777	6.0950	3.8908	.0095	.8334	.0927	15.0650	.3843	14.680
Central Caroline Islands-Hawaii	.2068	.0501	3.1233	1.4806	.6059	.0676	.6984	6.2327	.1498	6.082
-Angola, Africa	2.3914	.3545	6.0782	3.7334	.0773	.6246	.0018	13.2612	.3565	12.904
Hawaii-Angola, Africa	4.0048	.1380	.4873	.5118	.2504	.2812	.7711	6.4446	.3119	6.132
ΣD^2	41.0543	37.1912	128.5601	78.4819	20.8264	29.4377	33.4614			
Mean	.6220	.5635	1.9479	1.1891	.3156	.4460	.5070			
Σ means	.6220	1.1855	3.1334	4.3225	4.6381	5.0841	5.5911			
Ω	69	59	38	30	28	26	24			

the Angola and Costa Rica samples—length of the pectoral fin and heights of the second dorsal fin and the anal fins—all have significantly higher regression coefficients in the Angola samples and diverge more from the Costa Rica sample in the larger size groups.

Lastly, the sample from northeast Africa shows little overlap with any other sample. Such is to be expected because of the marked differenc fin lengths and distance from the snout t insertion of the anal fin, which have already pointed out. However, it has also been ment that this sample from northeast Africa wa composed of yellowfin of a size strictly compa to any of our size groups. Thus, much of differences may have arisen because of the e

TABLE 14.—*Percent of overlap* (Ω) *between areas, using seven characters*

a and size group	109°–119° W.	119°–129° W.	129°–139° W.	139°–149° W.	East Line Islands	West Line Islands	Phoenix Islands	East Marshall Islands	East Caroline Islands	Central Caroline Islands	Bikini Island	Japan	Hawaii	Angola, Africa	Northeast Africa
ica: M					18	13	7		3	3			23	45	
° W.: L		33	45	28	21	11	9	6	3	4			20	31	
° W.: L			71	52	27	24	21	12	11	12			38	62	
° W.: L				64	46	31	28	19	14	16			51	49	
° W.: L					55	47	39	23	18	23			52	42	
ne Islands:															
						80	46		17	16			19	36	
ne Islands:						51	48	39	26	34			52	19	
							71		21	15	11	36	17		4
							67		26	23			30	31	
Islands:							70	37	33	47			27	20	
									32	23	14	47	15		2
									44	42			31	21	
rshall Islands: L								65	55	55			29	14	
roline Islands:									53	56			23	7	
										70	14	51	16		.4
										82			27	10	
										81			21	6	
Caroline Islands:											14	49	17		.4
													30	11	
													22	7	
sland: S												25	28		3
S													39		2
															7
														41	
														22	

rvilinear regressions, and I cannot say with lence that this size group is as different as ata indicate.

EVALUATION OF MULTIVARIATE ANALYSIS

full evaluation of the merits of the multite analysis which I have used here is beyond cope of this article.[9] But the procedure is so ious that some discussion of the value of dering extra characters is warranted. The increases approximately in relation to the e of the number of characters, but Mahabis, Majumdar, and Rao (1949) refer to Mahabis, Bose, and Roy (1937),[10] in which it is n that D^2 approaches a limit as additional acters are considered. On an intuitive basis would be expected to happen rather quickly, use as additional characters are considered would have an increased chance of being lated with previously considered characters. extra amount of work involved in making the nalysis is approximately related to the square ne number of characters considered, so the lem is how many characters must be considered to arrive at a reasonably stable estimate of overlap.

It can be shown readily that more than one character must be considered. To demonstrate this, I have taken 10 comparisons at random out of the total of 122 and calculated the overlap of the single characters showing the greatest difference between samples. These, I compared with the overlap computed from seven characters (table 15). In all but one [11] there is a substantial reduction in the overlap due to the extra characters. In fact, the single character comparison with the least overlap, that between eastern Marshalls and Angola with respect to height of the anal fin, still shows an overlap of 40 percent. This is reduced to 7 percent when six more characters are added.

The average effect of adding characters one by one may be obtained from the grand average, D^2, for each size group. These averages have been obtained from table 13 for each character and the overlap computed, first for one character, then two characters, and so on until the seven are considered. It may be seen (fig. 20) that most

[9] etailed evaluation of the application of D^2 to an anthropometric survey found in Mahalanobis, Bose, and Roy (1937). t available to me.

[11] In this instance the seven characters show an overlap of 82 percent and the single character with the greatest difference shows an overlap of only 75 percent. This anomaly occurs because the other six characters when combined show less difference than the correction for small samples.

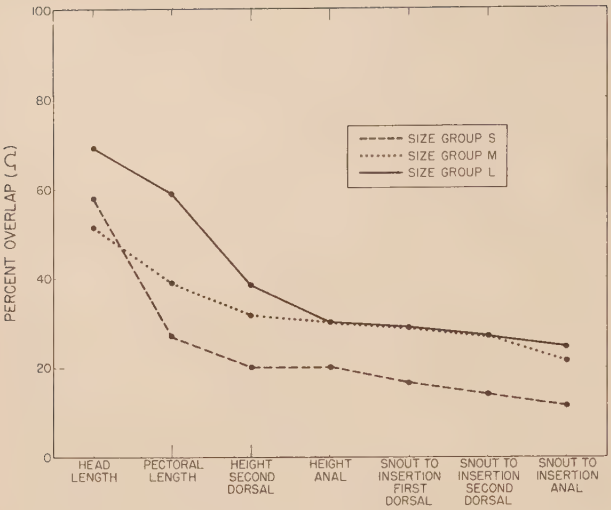


FIGURE 20.—Effect of adding characters on average overlap of all sample comparisons.

of the reduction (if any) in D^2 occurs in the first three or four characters, but that there is a continuing gradual reduction to the seventh character.

TABLE 15.—*Comparison of overlap of one character with overlap of seven characters considered simultaneously*

Sources of samples compared	Size group	Character showing greatest difference	Overlap (Ω)	
			1 character	7 characters
West Line Islands-Northeast Africa.	Small	Length of pectoral fin.	41	4
Bikini Island-Central Caroline Islands.	do	Height of second dorsal fin.	56	14
East Line Islands-Hawaii	Medium	Head length	59	19
East Caroline-Central Caroline Islands.	do	Snout to insertion of anal fin.	75	82
119°–129° West-East Line Islands.	Large	Height of anal fin.	54	27
129°–139° West-Phoenix Islands.	do	do	50	28
139°–149° West-Phoenix Islands.	do	do	55	39
Phoenix Islands-Hawaii	do	do	54	29
East Marshall Islands-Angola, Africa.	do	do	40	7
Hawaii-Angola, Africa	do	Head length	48	22

Another approach has been made in an examination of the character-by-character overlap of our most different, most similar, and moderately different equatorial samples (fig. 21). Here again it may be seen that in each case most of the reduction in overlap (if any) occurs in the first three or four characters.

It would also have been possible to improve the order in which I have considered the characters. The most useful characters are those that show the greatest difference among samples and the least

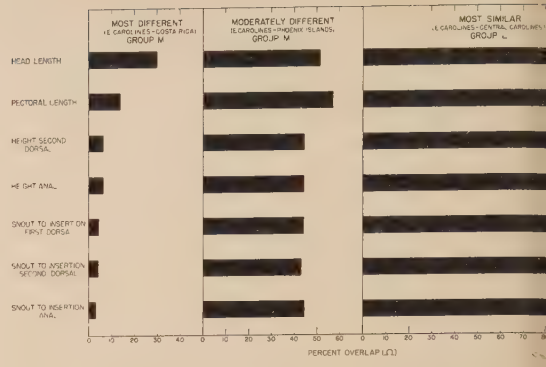


FIGURE 21.—Effect of adding characters on overl selected comparisons.

correlation with other characters. Thus, a sideration of our character-by-character com sons and the partial correlations of table 7 indi that it would be desirable to consider height anal fin, which is one of the characters showin greatest difference among samples, but not l of second dorsal fin, which is closely corre with the height of the anal fin. For a si reason I could have omitted the distance fro snout to insertion of the second dorsal fin considering that of the snout to insertion first dorsal fin, with which it is highly correl Another rather high correlation exists bet head length and distance from snout to inserti first dorsal fin.

Thus, it would appear that had I consi only the best four characters, I would have substantially the same overlap that I d considering seven. This would have reduce work of computation to about one-third of for the seven characters. Rao (1952: 256) also that it is profitable to use samples of equa

EXTENT OF INTERMINGLING

As I have previously argued, the percenta overlap of two samples may be considere represent the maximum proportion of one sa that might belong to the other. When this cept is extended to two populations sepa geographically, the overlap may be assumed the proportion of one which might have from the other. There is, of course, no evi that any part of the population did come another, but the overlap may be used, tog with other data, to estimate how much mingling might be occurring.

n use requires an assumption that the ters selected to estimate the overlap are If the characters are genotypic and fixed ie of fertilization, then the overlap would te a maximum amount of genetic mixing flow). Many characters, however, are fixed early development and vary according to nment, especially temperature. Even so, mount of overlap would still indicate a um possible amount of intermingling.

urly, between the two ends of the Pacific or the overlap is so small (3 percent) that can be practically no intermingling. Along ng belt where the yellowfin distribution is uous, I have previously noted that the e overlap is less than 50 percent in samples ted by 1,500 miles and less than 25 percent nples separated by 3,000 miles. Conse- y, it seems probable that east-west migra- nust be relatively limited and that most fin tuna probably remain within a few ed miles of where they occur as postlarvae. gs and larvae drift passively with the cur- but development is rapid and it seems ly that they could drift more than 300 or iles before becoming active swimmers.

ve noted previously that the average overlap samples was about the same for the different roups. This clearly indicates that after each a weight of about 5 pounds (50 cm.) is no tendency for samples of the larger fish ome more diverse. Such evidence indicates he morphological differences arise very early and considering the similar environment in urface layers along the Equator it seems ble that the differences are genotypic.

samples from farther away from the Equa- Bikini Island, Japan, and Hawaii—are sepa- from the Equator by a zone where yellowfin latively scarce. The Bikini sample shows overlap with samples from the adjoining orial areas, much less in fact than with the ese sample. The Hawaiian sample shows overlap with the smaller sizes from the equa- areas, but the larger sizes are quite like from the Equator southeast of Hawaii. is also considerable similarity between the ese sample and the Hawaiian sample.

sample from Angola, Africa, has so much p with some of the equatorial Pacific sam- hat the maximum amount of intermingling might be large, but of course the geographic separation makes absurd the suggestion of any intermingling. In the case of the northeast Africa sample, both the markedly low overlap with all other samples and the geographic separation make the possibility of intermingling very small.

GEOGRAPHIC DISTRIBUTION OF YELLOWFIN

One kind or another of yellowfin tuna, genus *Neothunnus*, has been described from each of the warm seas of the world except the Mediterranean. Rosa (1950) has reviewed the extensive literature and noted that the distribution extends from Point Conception, California, to San Antonio, Chile, in the eastern Pacific; from Hokkaido, Japan, south through the Indonesian Archipelago to Cape Naturaliste, southwest Australia; around the shores of the Indian Ocean to the tip of South Africa; from French Equatorial Africa north to the coast of Portugal in the eastern Atlantic, and from Maryland in the United States south to the coast of Brazil in the western Atlantic. He also reported that yellowfin occur in the Red Sea, which is the warmest sea in the world, so the distribution extends from the warmest waters to those in the vicinity of latitudes 40° N. and 40° S.

To these coastwise records must be added the records of capture in the open Pacific far from land, as reported by Yōichi Yabuta in the Japanese atlas "Average Year's Fishing Condition of Tuna Longline Fisheries," from the exploratory fishing of POFI along the central and eastern Pacific Equator, in offshore records from the eastern Atlantic by Mather and Day (1954), and in the more recent unpublished records of the capture of yellowfin tuna in the open parts of the Gulf of Mexico and Caribbean Sea by exploratory fishing vessels. The Japanese atlas records the capture of yellowfin tuna along the Equator from longitude 170° W. to the Philippines, thence northward at various places to as far as latitude 43° N. along the coast of Japan, in all of the major seas of the southwest Pacific, and in the Indian Ocean in the vicinity of Sumatra and the Nicobar Islands.

This distribution corresponds quite closely to that of waters warmer than the 65° F. isothere (line of equal warming) shown by Hutchins and Scharff (1947). Along the coast of Chile the limit is between the 65° F. and the 60° F. isotheres,

and in other areas the most poleward record is not quite to the 65° F. isothere. Further, no temperature barrier exists between any of the populations of yellowfin, for there is a broad band of summer temperatures between 65° F. and 70° F. around the Cape of Good Hope between the Atlantic and Indian Oceans.

Within the broad range of this species, however, there are widely varying concentrations. Already mentioned is the concentration along the Pacific Equator, where the yellowfin occur in an east-west band, and the scarcity in the open ocean north and south of this band. They do, however, occur in concentrations in the vicinity of many islands, in the Coral Sea off Australia, and possibly in other places separated from this equatorial belt by a region of yellowfin scarcity. The small yellowfin, in particular, seem to be concentrated fairly close to the islands, because they are rarely seen or caught on the high seas. The persistence of groups of these yellowfin along the reefs of certain islands has led to commercial fishing for them by trolling, and many fishermen feel that such yellowfin populations are relatively static. Thus, concentrations of yellowfin may vary enormously in extent from the clearly continuous distribution along many thousands of miles of the Pacific Equator to perhaps a relatively isolated group around a coral atoll.

Despite the variations in abundance, their widespread occurrence in all tropical oceans, near land and far from land, indicates that yellowfin tuna belong to the pelagic fauna of the warm seas and not merely to local faunal areas.

NOMENCLATURE

A great variety of scientific names has been assigned to yellowfin tuna in various parts of the world, and there has been no general agreement on the correct names to be assigned to the various species or subspecies. Rosa (1950) recognized three species: *Neothunnus albacora* (Lowe) 1839 of the eastern Atlantic Ocean, *N. argentivittatus* (Cuvier and Valenciennes) 1831 from the western Atlantic Ocean, and *N. macropterus* (Temminck and Schlegel) 1842 from the Pacific and Indian Oceans. Schaefer and Walford (1950) considered the Atlantic form to be *N. albacora* and the Pacific form to be *N. macropterus*. They designated a specimen from the Malabar coast of India as the lectotype of *N. argentivittatus*, and thus this name clearly applies to the Indian Ocean unless it is decided that the Indian Ocean should be the same species as one with a name from another ocean. Later Ginsburg considered that the name *Thunnus alb* (Bonnaterre) 1788 was appropriate for the e Atlantic yellowfin, *T. subulatus* (Poey) 18 the western Atlantic yellowfin, *T. ca* (Jordan and Evermann) 1926 for the e Pacific yellowfin, and *T. macropterus* (Tem and Schlegel) 1842 for the western yellowfin.

Rivas (1954: 316) referred in a footn Ginsburg's usage of *T. albacares* and accepte a valid name for all Atlantic yellowfin. (1961) reviewed the status of *T. albacares* and opined that the various yellowfin popul from the Atlantic and the Pacific were not w of separate nomenclaturial recognition. He the widespread distribution in tropical wate stated, ". . . it would seem therefore, th yellowfin tuna represents a single panti species . . . ."

The characters that almost all authors used to distinguish the species have been of the pectoral fin and height of the second and anal fins. Ginsburg (1953) admits th differences between the tuna of the eastern tic and Hawaii (which he calls western Pacif only of racial magnitude and do not w separate names. He retained the separate because he considered that (1) specimens two populations had not been directly com (2) not all promising phases of the morp had been studied, (3) the tuna inhabit different faunal areas, and (4) most author treated the populations as distinct species therefore, considered it desirable to avoi confusion of shifting names in and o synonymy.

Schaefer and Walford (1950) considere differences between the eastern Pacific and e Atlantic forms sufficient to warrant se species pending more information on the va ity within oceans as compared with the vari between oceans. This information is n hand from our studies and it shows clearl the entire range of variation which has here been used to describe the species of ye occurs within one continuous distributi yellowfin along the Pacific Equator. In

ifferences between yellowfin from Costa Rica from Angola (which Schaefer and Walford der to be sufficient for a separate species) are less than the differences between yellowfin Costa Rica and the eastern Carolines. This ence between the Costa Rican and Caroline ds yellowfin is far beyond the conventional of a subspecific difference, but because of the evidence of continuous distribution and hological gradients between these two areas ellowfin from the two areas must be con- ed conspecific.

ere also may be a similar cline across the cal Atlantic. Ginsburg (1953) reviewed the y evidence which indicates that the western tic form has longer second dorsal and anal han the eastern Atlantic form. If the cline resent, then the Atlantic forms, also, are ecific.

we add to this evidence the fact that the wfin is clearly a fish of the high seas and not icted to any coastal faunal areas and the g probability that the distribution is con- us in the oceans from the Pacific through the n to the Atlantic, all of the forms should be considered conspecific. The confusion can best be settled by reducing them to one species.

There will remain, of course, the possibility that certain yellowfin populations may be distinct enough to warrant a separate specific or subspecific name. This must be considered for the sample from northeast Africa off Somaliland, in which the fins are shorter than any we have found in the Pacific. However, our sample is not good, and with the evidence of continuous distribution through the Indian Ocean it seems most probable that this group is not completely separated from other yellowfin populations. Futhermore, it occurs in one of the warmest parts of the ocean, where the yellowfin would be expected to be the most different in structure.

Settling the matter of the proper specific name is only part of the problem. The generic name is also in dispute. Fraser-Brunner (1950) and Ginsburg (1953) used *Thunnus* rather than the long established generic name of *Neothunnus*. Godsil (1954) did not follow Fraser-Brunner but separated *Thunnus*, *Neothunnus*, and *Parathunnus*, principally on the basis of markings on the liver; however, he gives this problem of generic separation

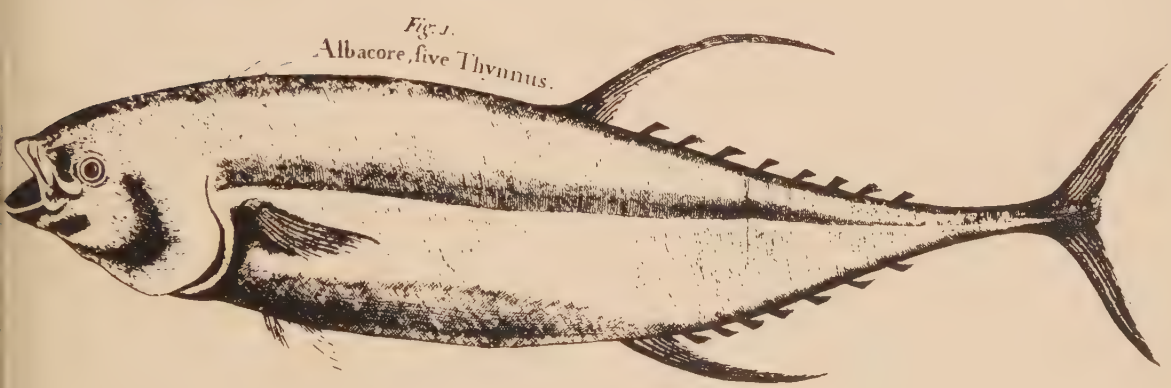


FIGURE 22.—Figure of tuna from Sloane (1707) on which Bonnaterre's description (1788) was based.

little consideration. Fraser-Brunner reduced *Parathunnus* and *Neothunnus* to subgeneric status on the principle that a generic name is intended to express relationship. It is not desirable to have a group of monotypic genera. There is now no evidence to indicate that these genera should be separate, and so I follow Fraser-Brunner and Ginsburg, who use *Thunnus* for the bluefin, yellowfin, bigeye, and albacore group.

The final question is which specific name is correct. Schaefer and Walford (1950) considered that *T. argentivittatus* (Cuvier and Valenciennes) 1831 would have priority if only one species of yellowfin was recognized, but they did not discuss the merits of *T. albacares* (Bonnaterre) 1788. Ginsburg (1953) reviewed the question and concluded that the original figure of *albacares*, which shows the distinctive long second dorsal and anal fins of the yellowfin, must be considered a yellowfin even though the pectoral fin is too short. Bonnaterre's description of the yellowfin was based on a description and figure by Sloane (1707) which I reproduce here in full (fig. 22).

The Sea hereabout is very well provided with *Albacores*, or *Thynni*, whose Description follows:

ALBACORES DESCRIBED

This Fish was Five Foot long from the end of the Chaps to that of the Tail, the Body was of the make and shape of a Mackerel, being roundish or torose, covered all over with small Scales, White in some places, and Darker colour'd in others, there was a Line run along each side. The coverings of the Gills of each side were made of two large and broad Bones covered with a shining Skin, the Jaws were about Six Inches long, having a single row of short strong sharp Teeth in them, and were pointed. The Eyes were large, and the Gills very numerous, behind which were a small pair of Fins. *Post anum* was a Foot long Fin, about Three Inches broad at bottom, and Tapering to the end. It had another on its Back answering that on the Belly, and from these were small *Pinnula* at every Two Inches distance to the forked Tail, which was like a New Moon falcated, before which on the Line of the two sides was a membranous thick horny Substance, made up of the Fishes Skin, stood out about three quarters of an Inch where it was highest, something like a Fin. It was about Three Foot Circumference a little beyond the Head, where it was thickest. The Eye was about an Inch and a half Diameter. The Figure of this Fish is here added, *Tab.* I. *Fig.* I. taken from a dried Fish, where every thing was perfect save the first Fin on the Back, which I suppose was accidentally rub'd off.

It is frequently taken by Sailers with Fisgigs or White Cloath, made like Flying-Fish, and put to a Hook and Line for a Bait; The Flesh is coloured, and Tasts as the *Tunny* of the Mediterranean, from whence I am apt to believe it the same Fish. It is to be found not only a *Spain*, and in the way to the *West-Indies;* but in the So Seas about *Guayaquil*, and between *Japan* and *New-S* every where.

This is called *Tunnyes* of *Oviedo fum. p.* 214. *Alb* of *Terry, p.* 9. *Albocores* of *Mandelflo, p.* 196. *Do* or *Tunin of Marten, Orcynus Rondelet, p.* 249. *Thu Gesner.* 1158. *Aldrovand. p.* 307. *Mus. srammerd. Hist. p.* 176. *Tab. M.* I. *Corett. Thynni Species e app. p.* 5. & 24. *Tab.* 9. *No.* I. where the Figure s not good. *Thynnus Bellon. p.* 106. *Salvian. p.* 124. *palamite of Oviedo Sum. p.* 211? *Guarapucu Brasiliens an Cavala Lusitanis, nostratibus Coninghvisch. Ma p.* 178? *Pif. Ed.* 1658. *p.* 59? *vel an Curvata pi ejusd. p.* 150? *Ed.* 1650. *p.* 51? *Tons* of *Escarbot Francia, p.* 35. *du Raveneau de Lussan, p.* 171. *An coretta Pis. Ed.* 1658. *p.* 73? *Toni di Fernan Colon vi Christof. f.* 29. An Ox-Eye of *Anonymus Portugal Purchas, p.* 1313? *vel Toninas Ejusd. ib. p.* 1314? *nies of Francis Gualle. Purchas,* 806. *Albacoras Ejus* 446. *Hakl.* of *Smith New-England, p.* 227. of *Gal Purchas,* in 42°. North Lat. South-Seas, *p.* 1685. *ou tasard de Cauche, p.* 138. *An tonine Ejusd. p. Ulasso* a Tuny Fish of *Duddeley. p.* 576. *Albaco Ligon. p.* 6. *Abbeville. p.* 30. *An* a *Spanish* Macq of *Ligon*? *Albachores Pyrard. de Laval. p.* 6. 137.

A tuna of the size of Sloane's specimen al certainly must have been one of either the yel fin or the bluefin group. A comparison of m urements of Atlantic bluefin, Angola yellowfin, Sloane's figure (table 16) indicates that Sloa figure is closer to the yellowfin than to the blu in all characters except length of the pectoral Further, Sloane's figure was taken from a d fish from which the first fin on the back was n ing and his figure is a dorsolateral view instea a lateral one. These facts explain most of differences from an accurate sketch of a yello which include the shorter pectoral fin, shorter

TABLE 16.—*Comparison of body proportions calcu from Sloane's figure of Albacore, yellowfin from An Africa, and bluefin tuna from Cape Cod, Mass.*

[Expressed as thousands of fork length]

Character	Sloane's figure [1]	Yellowfin [2]	Atla blue
	cm.	*cm.*	*cm*
Fork length	152	140	125.7
Head length	212	258	284
Length of pectoral fin	135	256	197
Height of second dorsal fin	270	249	132
Height of anal fin	197	268	129
Snout to insertion of—			
First dorsal fin	190	280	306
Second dorsal fin	489	509	541
Anal fin	580	559	606
Ventral fins	276	286	315

[1] From Sloane (1707) fig. 1, table 1.
[2] From Schaefer and Walford (1950), using the regressions for our lar group and assuming a fork length of 140 cm.
[3] From Godsil and Holmberg (1950), page 7, converted from their ra part size to body length.

nore slender body, and first dorsal fin too far ard.

herefore, I concur with Ginsburg and conclude *T. albacares* (Bonnaterre) 1788 is a valid name ellowfin tuna. It has priority and hence the opriate name for a single worldwide species of wfin tuna is *Thunnus albacares* (Bonnaterre) .

SUMMARY AND CONCLUSIONS

he study was undertaken in order to under- d better the intermingling of the populations ellowfin tuna and to distinguish the species.

wenty-four samples of yellowfin tuna from the fic Ocean, one from the Atlantic off Angola, ca, and one from the Indian off Somaliland compared.

egression statistics are used to control effect ze of fish in order to compare samples by each en characters. Seven of the characters are ner used in a multiple character measure of lap.

he regression equations used by Schaefer (1948) used. These require log of fork length with height of second dorsal fin and log height of fin, and log fork length with length of pectoral All other characters approximate a linear tionship.

either linear, transformed linear, nor simple ilinear regression equations are completely sfactory for the full range of the data. There- , samples are divided into small fish, less than m.; medium, 80 to 120 cm.; and large, more 120 cm. in fork length. Comparisons are e at 65 cm., 100 cm., and 140 cm., respectively.

cline, or character gradient, exists along the ific Equator from the eastern Pacific to the oline Islands. The yellowfin in the eastern ific have larger heads, slightly shorter pectoral much shorter second dorsal and anal fins, greater distances from snout to the insertion of dorsal, second dorsal, ventral, and anal fins. y also have a greater body depth and a greater ance from the insertion of the ventral fins to vent.

Most other samples were like some part of the e. The sample from Angola, Africa, closely mbled the samples taken between Costa Rica the Line Islands. The samples from Hawaii e quite like those taken between longitude ° W. and the Line Islands. The sample from Japan was like the one from the Caroline Islands. The Bikini Island sample, however, was rather unlike the others but most similar to those from Japan and Hawaii. The Philippine sample was most like samples from the eastern Pacific and very different from the nearby Caroline Islands samples. Most diverse was the sample from Somaliland, which had especially short fins, deep body, and a long distance from the snout to the insertion of the ventrals.

The overlap of samples from along the Pacific Equator is inversely related to distance between samples. The average between samples taken 1,500 miles apart is less than 50 percent; 3,000 miles apart, less than 25 percent; and 6,000 miles apart, less than 6 percent. It is concluded that east-west migration is limited and that most yellowfin remain within a few hundred miles of where they occur as juveniles.

The multivariate analysis is evaluated. It is shown that overlap is greatly reduced by considering more than one character but that it is not worthwhile to use more than four characters.

The distribution of the yellowfin indicates that it belongs to the pelagic faunal group and not to coastal faunal groups. It occurs in all oceans, except the Mediterranean, in waters warmer than 65° F. at the surface. No temperature barrier to movement of the yellowfin exists between the Atlantic and Indian or Indian and Pacific Oceans. The distribution is probably continuous although not uniform.

It is considered desirable to place all yellowfin tunas of the world in a single species because of the continuous distribution and because the full range of characters which have been used to distinguish species occurs in the series of samples from the Pacific Equator. The name should then be *Thunnus albacares* (Bonnaterre) 1788.

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My debt to the many people who have carefully measured thousands of tuna is detailed in a previous paper (Dung and Royce, 1953). The formidable task of analyzing the data has been accomplished almost entirely by Mrs. Dorothy D. Stewart, nee Dung. Joseph J. Graham, Garth I. Murphy, O. E. Sette, and A. L. Tester critically reviewed the manuscript.

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APPENDIX

LE A–1.—*Morphometric measurements of yellowfin tuna (mm.), from longline catches near the Equator and longitude 110° W., March 1954*

Fork length	Weight (lb.)	Head length	Snout to insertion of—				Insertion of ventral fin to anterior edge of vent	Greatest body depth	Length of pectoral fin	Height of—		Diameter of iris	Sex	Examiner
			First dorsal fin	Second dorsal fin	Anal fin	Ventral fin				Second dorsal fin	Anal fin			
------	------	217	243	416	454	238	------	188	207	98	99	33	F	William F. Royce.
------	23¼	223	242	430	479	243	242	214	225	113	113	30	M	Do.
------	------	228	247	435	487	252	235	202	242	119	119	31	F	Do.
------	------	288	310	552	605	319	------	278	284	180	186	38	M	Do.
------	------	310	342	616	678	350	343	306	309	222	205	36	F	Do.
------	------	309	334	605	678	333	------	300	310	229	246	40	F	Do.
------	------	308	341	627	689	344	353	293	322	218	213	34	F	Do.
------	------	314	339	623	692	353	346	303	308	216	234	35	F	Do.
------	------	325	359	661	733	365	377	311	330	276	269	36	F	Do.
------	------	350	387	722	791	391	------	348	336	363	434	40	F	H. S. H. Yuen.
------	------	367	417	735	819	411	------	375	341	368	465	41	M	Do.
------	------	360	400	732	816	399	428	380	356	378	416	41	M	William F. Royce.
------	------	367	394	779	819	404	421	362	380	396	381	44	F	Do.
------	------	366	383	737	817	400	448	388	343	366	319	38	M	Do.
------	------	379	416	765	844	420	441	391	369	379	404	40	F	H. S. H. Yuen.
------	------	369	391	756	840	419	427	379	358	363	393	38	F	Do.
------	------	388	417	767	851	431	445	382	347	362	443	42	F	Do.
------	------	385	425	764	853	430	433	398	378	391	465	40	M	Do.
------	------	404	445	781	858	454	------	417	371	446	512	42	M	Do.
------	------	379	420	777	846	417	------	400	379	417	434	45	M	William F. Royce.
------	165	387	429	791	880	428	461	411	[1] 361	------	592	42	F	H. S. H. Yuen.
------	------	408	437	813	893	459	452	420	367	506	[1] 0	41	M	Do.
------	------	408	430	803	913	466	457	417	358	458	543	40	M	Do.
------	------	415	450	828	906	454	470	429	391	420	502	41	M	Do.
------	------	435	457	828	908	472	453	427	375	477	362	40	M	Do.
------	200	429	438	841	937	471	478	445	404	493	543	42	M	W. F. Royce.
------	220	427	483	871	957	471	508	454	406	640	716	46	M	Do.

Frayed.

TABLE A–2.—*Morphometric measurements (cm.) of yellowfin tuna taken near Bender Cassim, Somaliland, Afric*

[Measured by A. Fraser-Brunner]

Fork length	Weight (kg.)	Head length	Snout to insertion of—				Insertion of ventral fin to anterior edge of vent	Greatest body depth	Length of pectoral fin	Height of—		Diameter of iris	Number of gill rakers	Sex	Months
			First dorsal fin	Second dorsal fin	Anal fin	Ventral fin				Second dorsal fin	Anal fin				
62.5	5.25	18.5	20.5	34	39	23		16.5	16.5	7	6.5	2.5	9+18	M	March.
65	6.3	18.75	20	35.5	40	21.5		17	18	7.25	7.5	3	8+20	M	Februar
65	6.4	19	21	36	40	21.5		17	18	8.5	8	3.5	9+18	F	January
65	6.4	19	21.5	36.5	39.5	21		17	17.5	9	9	3.5	9+18	F	Februar
67.5	6	19.5	22.5	37.5	42	22		17	18.5	8.5	9	3	10+19	F	Do.
68	6	19.5	23	38	42	22		17.5	18.5	8.5	9	3	10+19	F	January
69.5	6.4	20	21.5	38	42	22		18.5	19	9.5	10	3.25	10+21	M	Februar
70	5.6	20	24	41	44	23		20	19.5	8.5	8	3	8+20	M	January
70	5.8	20	22	29	43	22		17.5	18	8.5	8	3.5	10+18	F	March.
70	7	20	22	29	43	22		17.5	18	8	8.8	3.5	9+19	F	Do.
70.5	5	20	23	39	42.5	23		18.5	19	8.5	8	3	9+20	F	January
70.5	5.4	20.5	22	38	42.5	23.5		18.5	18.5	8.5	8	3	9+20	M	Februar
70.5	5.8	20	23.5	39	43	23		19	20	9	8	3.5	9+20	F	January
71.5	7.8	20.5	22.5	39	43	23.5		19	18.5	8.25	9	3.5	9+20	F	March.
72	7	20.5	22.5	39.5	43	23		19	20	8	8.5	3.5	10+20	M	Do.
73	8	20.5	22.5	38	45	24		19	19.5	10	10	3.25	9+20	M	Do.
73	8	20.5	22	37.5	45	24		19	19.5	9.5	10	3.5	9+20	M	Do.
73.5	7.3	20.5	23	39	44	23.5		19	19.5	8.5	8.5	3	9+20	F	Do.
74	8	21	25	42	45	24		20	20	9	11	3.5	9+20	F ?	Februar
74	8	21	24	41	45.5	25		20	20	9	10	3.5	9+20	M	March.
75	7.7	21.5	23	41.5	46	24		19.5	20	9.5	10	3.5	9+19	F	Do.
76	5.5	18.5	21	36	40	21		16.5	19	8	8.25	3.5	9+21	M	Do.
76	6	18.5	21	35	40	21.5		16.5	13	8.5	8.25	3.5	9+21	M	Do.
76	9	22	24.5	42	46	25		20.5	21.5	10	11.5	3.5	9+22	F	Do.
77	5.5	19	21.5	36.5	40.5	22		17	19	8	8.5	3.5	9+20	M	Do.
80	10	23	24	42.5	49.5	26		22	20	11.25	12	3.5	9+20	F	Do.
80	10	23	24	42.5	49	25		22	20	11	11.5	3.75	10+20	F	Do.
80	11	23	26	44	48.5	26		22	21.5	11	12	4	9+20	F	Do
80	11	23	26	44	48	26		22	21.5	11	12	4	9+21	F	Do.
80.5	10	22.5	25	44	48	26		21	20.5	9.5	10	4	9+21	F	Do.
80.5	10	22.5	25	44	48	26		21	20	9.5	10	4	9+22	F	Do
81	10	23	25.5	44	47	25.5		21	21	9	11	3.5	8+20	M	Do
81	10	23	24	43	50	26		22.25	20	11.5	12	3.75	9+20	F	Do
81	10.7	23	25.5	44	47	25.5		21	21	9	11	3.5	9+20	M	Do.
81.5	10	23	25	43.25	44	27		20.5	22.5	9.5	10	4	10+22	F	Do.
81.5	10	24	26.5	44	49	25		22	20.5	9.5	12	3.5	10+21	F	Do.
82	11.6	24	27	45.5	49	26		21.5	23.5	10.5	12.5	4	10+22	M	Do.
82.5	10.5	22.5	24	43.5	46.5	24		22	22.5	12	14	3.5	9+20	M	Do.
83	11.5	23	25.5	44.5	50	26.5		22	21.5	11	12	3.5	9+20	F	Do.
83	11.7	23.5	25.5	44.5	50.5	26.5		21.5	21.5	11	11.5	3.5	9+20	F	Do.
84	11	22.5	26	45	50	26.5		22.5	22	11	13	3.5	9+20	F	Do.
84	11.8	23.5	25.5	44.5	50.5	26.5		21.5	21.5	11	11	3.5	10+20	F	Do.
84	12	24	26.5	45	50	27		23	21	11	12	4	10+20	M	Do.
84	12	24.5	26	46	50	27		22.5	21	10.5	11.5	4	9+20	M	Do.
84	12.6	24	27	45	50.5	27		22.5	21	11	12.5	4.25	9+21	M	Do.
84.5	12	24.5	26	47	52	28.5		23	23	12.5	16.5	3.5	8+20	F	Do.
84.5	12	23	26	45.5	50.5	26.5		22	21.5	11.5	11.5	4	9+21	M	Do.
84.5	12.7	23	26	45.5	50.5	26.5		22	23	11.5	11.5	4	8+21	M	Do.
85.5	12	23.5	26.5	45	51	26		22.5	22	11	14	4	10+20	F	Do.
86	12	23.5	27	45	49	26		23	22	11.5	10.5	4	8+21	F	Do.
86	13	24	27.5	46.5	52.5	27.5		23	24	12 5.	14	3.5	9+20	M	Do.
86	13	24	27	46.5	51	27.5		23	22	12	13	4	10+20	F	Do.
87	13	24.5	26.5	45.5	50.5	26.5		23.5	22	12	12	4	9+22	F	Do.
87	13.3	24.5	27	46	52	27.5		23	24.5	13	14.5	3.75	9+20	M	Do.
89	14	26	28	48	52	29		24	23	13.5	15	4	8+20	F	Do.
105.5	22	28	31.5	56	61	31.5		27	26	16	18	4	9+20	M	Do.

NOTE.—Data furnished through the courtesy of G. L. Kesteven, Fisheries Division, U.N. Food and Agriculture Organization. Measurements w
corded in half or quarter centimeter units identified by the upper limit of each unit; thus are ⅛ to ¼ cm. too great.

TABLE A-3.—*Regression statistics of yellowfin tuna samples*

mber used in sample; S=summation; X=fork length (mm.) or log. (mm.); Y=other characters as listed; x=deviations from mean $\bar{x}$; y=deviation from an $\bar{y}$; b=regression coefficient; a=constant in regression equation; s=standard deviation from regression (cm.); $\hat{Y}$=estimated character size (cm.) at standard comparison length of size group (cm. except for logarithms which have characteristics for mm.)]

Character and size group [1]	N	SX	SY	SX^2	SY^2	SXY	Sx^2
k length; Y=head length:							
a Rica: [2] M	29	2,896.5	789.9	292,493.79	21,688.87	79,625.98	3,193.3676
119° W.: L	21	3,146.2	797.0	475,009.34	30,504.64	120,353.68	3,648.6524
–129° W.: L	47	6,895.9	1,739.1	1,016,781.01	64,638.71	256,300.39	5,005.7588
139° W.: L	46	6,667.6	1,680.6	988,059.18	62,520.78	248,469.53	21,605.0548
-149° W.: L	111	16,507.1	4,150.5	2,468,765.29	156,032.57	620,546.47	13,951.3223
Line Islands:							
	33	3,382.8	913.8	349,710.50	25,445.64	94,305.02	2,942.7473
	155	22,524.5	5,631.8	3,288,056.75	205,463.66	821,786.66	14,810.9420
t Line Islands:							
	43	2,954.4	849.3	205,448.86	16,939.55	58,973.52	2,460.9680
	86	8,407.2	2,286.3	832,615.32	61,334.71	225,881.39	10,743.0894
	57	7,876.2	1,998.8	1,094,133.62	70,433.44	277,547.24	5,808.5948
ıyra Island: [3]							
	35	2,537.2	730.7	184,770.90	15,308.81	53,170.94	845.6475
	57	5,379.7	1,446.6	511,367.03	36,886.28	137,303.18	3,627.1688
enix Islands:							
	37	2,503.6	715.2	171,117.96	13,927.34	48,798.54	1,712.2044
	59	5,795.3	1,559.6	576,982.99	41,586.04	154,811.32	7,737.1918
	46	6,142.5	1,539.6	836,866.39	52,633.16	209,836.18	16,642.3411
Marshall Islands: L	40	5,453.4	1,359.8	746,253.02	46,398.12	186,058.56	2,763.7310
ni Island: S	31	1,829.9	520.9	109,843.77	8,859.57	31,185.95	1,826.5439
Caroline Islands:							
	60	3,916.3	1,096.1	259,183.29	20,224.83	72,382.71	3,559.8619
	55	5,404.4	1,411.5	539,532.20	36,602.69	140,475.74	8,486.0298
	54	7,516.0	1,872.4	1,052,115.44	65,213.40	261,891.54	5,999.5882
ral Caroline Islands:							
	37	2,513.9	698.9	173,346.55	13,369.39	48,132.23	2,544.0309
	102	10,289.2	2,673.5	1,049,698.10	70,639.51	272,240.75	11,780.0938
	69	9,125.8	2,287.5	1,211,069.54	76,126.13	303,577.84	4,109.7482
ippines (SW. Panay):							
	242	15,776.4	4,550.2	1,040,719.56	86,405.94	299,786.77	12,228.6635
	81	7,349.8	1,993.6	674,621.22	49,439.00	182,526.67	7,713.0714
	32	4,234.2	1,085.1	562,353.60	36,933.97	144,065.00	2,089.5488
n: S	31	1,789.5	508.7	108,296.33	8,686.13	30,660.85	4,995.9994
aii: [2]							
	36	1,884.6	534.2	100,518.50	8,061.62	28,461.45	1,859.6900
	34	3,466.4	913.2	356,040.12	24,662.30	93,673.95	2,630.4448
	133	19,955.4	4,929.5	3,028,042.30	184,479.19	747,259.96	33,922.0808
aii: [3]							
	47	2,679.3	762.9	153,111.13	12,412.53	43,589.67	373.9281
	20	2,859.2	714.2	409,803.42	25,588.64	102,393.11	1,052.1880
ty Islands: S	17	988.5	284.4	58,503.31	4,827.06	16,801.56	1,024.9424
theast Africa: S	48	3,805.0	1,077.3	304,447.00	24,356.69	86,085.00	2,821.4792
ola, Africa: [4]							
	21	2,050.5	560.5	206,277.69	15,248.01	56,039.06	6,061.0115
	27	3,717.0	961.3	515,125.62	34,411.43	133,110.49	3,418.6200
ctoral fin length:							
a Rica: [2] M	28	83.897	755.5	251.444377	20,519.41	2,266.4008	.061998
-119° W.: L	21	66.650	758.0	211.566268	27,490.42	2,407.5195	.031863
129° W.: L	46	154.626	1,680.7	461.064214	61,652.59	5,322.9928	.043956
-139° W.: L	46	145.115	1,650.4	458.098769	60,123.18	5,222.2868	.308265
-149° W.: L	113	358.339	4,216.1	1,136.467083	157,636.55	13,374.0386	.123376
Line Islands:							
	124	391.907	4,570.7	1,238.755335	168,894.65	14,450.0028	.117459
	32	96.266	917.8	289.652924	26,501.70	2,763.9444	.054713
t Line Islands:							
	43	121.882	874.9	345.577724	18,022.45	2,484.4753	.107447
	86	256.925	2,418.1	767.775975	68,804.05	7,236.1381	.212538
	56	175.831	2,030.0	552.137153	73,803.70	6,376.8446	.056072
enix Islands:							
	37	104.643	751.9	296.022337	15,457.43	2,129.8423	.072136
	58	173.291	1,696.1	517.898774	50,125.13	5,075.4469	.144108
	46	143.943	1,643.0	450.460353	58,862.76	5,142.9820	.034544
Marshall Islands: L	40	125.349	1,441.5	392.839243	52,058.77	4,518.3636	.029948
ni Island: S	31	85.798	558.8	237.546178	10,226.10	1,550.0649	.084991
Caroline Islands:							
	60	168.697	1,239.1	474.472711	25,954.71	3,491.1148	.161415
	53	158.390	1,568.3	473.500596	46,927.19	4,695.2196	.153576
	53	173.007	2,023.5	544.271157	74,624.13	6,367.6164	.063484
tral Caroline Islands:							
	36	101.854	778.3	288.288240	17,128.15	2,207.7750	.114982
	102	306.117	3,125.4	918.930769	96,471.08	9,391.1201	.228635
	72	224.688	2,576.1	701.222332	92,354.33	8,040.8810	.054980
n: S	30	82.441	515.3	226.832298	9,385.21	1,428.2000	.281682
aii: [2]							
	36	97.754	550.6	265.544952	8,636.70	1,499.6342	.104827
	34	102.230	990.4	307.429448	29,046.90	2,980.3779	.047893
	133	422.105	5,032.9	1,339.929970	191,379.69	15,986.6720	.286128
ety Islands: S	21	57.897	374.4	159.676581	6,854.34	1,035.2576	.054552
theast Africa: S	48	139.053	999.5	402.913285	20,984.25	289.8690	.085435
ola, Africa: [4]							
	21	62.646	569.8	187.000176	15,924.06	1,707.0178	.118209
	27	84.710	953.7	265.799772	33,330.51	2,993.9101	.029991

otnotes at end of table.

TABLE A–3.—*Regression statistics of yellowfin tuna samples*—Continued

Character and size group [1]	*N*	*SX*	*SY*	SX^2	SY^2	*SXY*	*Sx* [2]
Y=height second dorsal fin:							
Costa Rica: [2] *M*	28	83.896	61.318	251.435890	134.538996	183.841218	0.
109°–119° W.: *L*	20	63.455	51.701	201.358243	133.893361	164.117955	
119°–129° W.: *L*	45	142.407	116.934	450.704783	304.507574	370.192937	
129°–139° W.: *L*	45	141.932	115.801	447.967280	299.620879	365.902722	
139°–149° W.: *L*	109	345.664	287.463	1,096.300848	759.324805	911.908839	
East Line Islands:							
M	32	96.220	72.790	289.372416	165.827650	218.957612	
L	155	489.958	412.957	1,548.906650	1,102.197991	1,305.785473	
West Line Islands:							
S	42	119.137	83.006	338.044643	164.358096	235.620544	
M	84	250.789	189.036	748.954439	426.449708	564.797120	
L	57	178.935	149.275	561.771969	391.669033	468.777214	
Phoenix Islands:							
S	36	101.821	71.606	288.058653	142.698836	202.657672	
M	55	164.262	125.241	490.710168	285.685185	374.264864	
L	44	137.612	114.589	430.427680	298.849489	358.489012	
East Marshall Islands: *L*	38	119.107	100.708	373.357959	267.224844	315.739082	
Bikini Island: *S*	30	82.938	55.723	229.368553	103.721167	154.177996	
East Caroline Islands:							
S	60	168.697	118.869	474.472711	235.963849	334.477887	
M	55	164.390	126.919	491.509308	293.653623	379.691955	
L	54	169.785	144.748	533.898401	388.441770	455.251731	
Central Caroline Islands:							
S	36	101.779	72.384	287.862165	145.852994	204.828458	
M	102	306.117	237.642	918.930769	554.766056	713.671426	
L	71	221.566	185.713	691.475448	486.391527	579.669959	
Japan: *S*	31	85.269	57.732	234.830567	108.176324	159.229245	
Hawaii: [2]							
S	33	89.605	59.351	243.40909	106.99218	161.30666	
M	34	102.231	77.106	307.43281	175.05126	231.91726	
L	133	422.105	352.442	1,339.93162	936.08809	1,119.25091	
Society Islands: *S*	20	55.062	37.280	151.647056	69.692726	102.737708	
Northeast Africa: *S*	43	124.960	86.819	363.189526	175.472595	252.384244	
Angola, Africa: [4]							
M	20	59.739	44.580	178.549527	99.720328	133.352250	
L	26	81.631	65.771	256.319531	166.546780	206.553552	
Y=height anal fin:							
Costa Rica: [2] *M*	28	83.898	62.249	251.448856	138.676825	186.641229	
109°–119° W.: *L*	20	63.445	52.351	201.294243	137.360109	166.158030	
119°–129° W.: *L*	46	145.618	121.359	461.013894	320.731273	384.301592	
129°–139° W.: *L*	44	138.731	115.337	437.720969	304.022121	364.330992	
139°–149° W.: *L*	110	348.752	295.097	1,105.828784	792.763031	935.861205	
East Line Islands:							
M	33	99.292	76.066	298.809600	175.647828	228.981829	
L	153	483.531	414.601	1,528.254051	1,125.407081	1,310.662739	
West Line Islands:							
S	42	119.118	83.219	337.939288	165.233633	236.198792	
M	87	259.891	199.596	776.573131	459.480550	596.750578	
L	54	169.496	144.323	532.067676	386.427807	453.165245	
Phoenix Islands:							
S	37	104.641	73.489	296.010719	146.301409	207.982031	
M	58	173.326	134.937	518.112303	314.633461	403.515203	
L	43	134.444	114.370	420.379512	304.506932	357.661681	
East Marshall Islands: *L*	39	122.276	105.833	383.395914	287.459047	331.880495	
Bikini Island: *S*	31	85.907	57.758	238.182920	108.065174	160.283217	
East Caroline Islands:							
S	60	168.697	119.181	474.472711	237.383145	335.404648	
M	55	164.390	129.428	491.509308	305.394016	387.198621	
L	52	163.420	142.437	513.642164	390.578717	447.776963	
Central Caroline Islands:							
S	35	99.042	70.543	280.380896	142.657533	199.846930	
M	101	303.205	239.524	910.451025	569.235948	719.542609	
L	70	218.412	187.800	681.527732	504.318644	586.077836	
Japan: *S*	30	82.632	55.604	227.876798	103.864654	153.619860	
Hawaii: [2]							
S	34	92.360	60.270	250.99237	107.19607	163.90159	
L	133	422.105	358.549	1,339.93164	968.75793	1,138.64039	
M	34	102.239	78.230	307.48041	180.25731	235.32153	
Society Islands: *S*	19	52.360	35.319	144.346252	65.858589	97.429882	
Northeast Africa: *S*	43	124.960	88.273	363.189526	181.467413	256.620348	
Angola, Africa: [4]							
M	21	62.646	46.863	187.000176	105.043883	140.028416	
L	27	84.710	69.103	265.801668	177.057928	216.862426	
Y=snout to insertion first dorsal fin:							
Costa Rica: [2] *M*	29	2,896.5	853.9	292,493.79	25,390.27	86,162.62	3,193.
109°–119° W.: *L*	21	3,146.2	865.8	475,009.34	35,969.34	130,656.84	3,648.
119°–129° W.: *L*	44	6,450.3	1,784.5	950,350.67	72,671.25	262,735.30	4,751.
129°–139° W.: *L*	46	6,667.6	1,848.3	988,059.18	75,600.75	273,216.64	21,605.
139°–149° W.: *L*	112	16,645.1	4,573.0	2,487,698.53	187,782.94	683,312.55	13,954.
East Line Islands:							
M	33	3,382.8	981.3	349,710.50	29,370.83	101,318.62	2,942.
L	155	22,538.9	6,152.4	3,292,495.07	245,222.02	898,248.44	15,062.
West Line Islands:							
S	44	3,022.1	935.9	210,032.15	20,100.84	64,948.35	2,461.
M	86	8,402.3	2,459.2	831,632.87	70,984.24	242,859.66	10,718.
L	55	7,576.8	2,068.7	1,049,124.22	78,177.79	286,342.03	5,344.
Palmyra Island: [3]							
S	35	2,537.2	797.5	184,770.90	18,240.39	58,031.19	845.
M	57	5,379.7	1,586.9	511,367.03	44,399.43	150,634.50	3,627.
Phoenix Islands:							
S	35	2,384.8	740.5	164,052.42	15,795.21	50,893.93	1,558.
M	59	5,795.3	1,690.9	576,982.99	48,913.93	167,924.19	7,737.
L	45	6,069.5	1,670.0	822,105.79	62,171.48	22,601.378	3,465.

See footnotes at end of table.

TABLE A–3.—*Regression statistics of yellowfin tuna samples*—Continued

Character and size group [1]	*N*	*SX*	*SY*	SX^2	SY^2	*SXY*	Sx^2
Marshall Islands: *L*	39	5,310.9	1,461.4	725,946.77	54,957.40	199,720.51	2,724.7493
i Island: *S*	31	1,829.9	560.6	109,843.77	10,254.82	33,547.13	1,826.5439
Caroline Islands:							
	59	3,861.4	1,189.4	256,169.28	24,203.44	78,707.02	3,450.4672
	55	5,404.4	1,560.8	539,532.20	44,782.08	155,380.26	8,486.0298
	56	7,837.2	2,150.0	1,103,798.16	83,008.82	302,614.71	6,982.0200
al Caroline Islands:							
	35	2,378.7	729.8	163,986.53	15,390.80	50,225.33	2,323.2818
	102	10,289.2	2,955.1	1,049,698.10	86,320.21	300,905.71	11,780.0938
	71	9,404.3	2,597.7	1,249,939.11	95,321.55	345,077.67	4,293.2158
pines (SW. Panay):							
	242	15,776.4	5,121.5	1,040,719.56	109,406.73	337,258.66	12,228.6635
	81	7,349.8	2,232.5	674,621.22	61,959.87	204,321.76	7,713.0714
: *S*	33	4,388.7	1,243.0	586,223.85	47,014.72	165,933.26	2,566.6473
ii: [2]	31	1,789.5	564.0	108,296.33	10,681.40	33,999.64	4,995.9994
	36	1,884.6	601.8	100,518.50	10,234.96	32,067.13	1,859.6900
	34	3,466.4	1,015.2	356,040.12	30,484.58	104,134.53	2,630.4448
ii: [3]	131	19,610.4	5,379.7	2,968,469.30	222,997.89	813,401.91	32,837.3299
	47	2,679.3	834.6	153,111.13	14,856.44	47,686.86	373.9281
y Islands: *S*	20	2,859.2	794.0	409,803.42	31,624.14	113,819.11	1,052.1880
east Africa: *S*	22	1,260.6	400.2	73,377.44	7,375.30	23,254.99	1,145.0600
a, Africa: [4]	48	3,805.0	1,189.5	304,447.00	29,713.75	95,067.25	2,821.4792
	21	2,050.5	606.8	206,277.69	17,860.48	60,639.16	6,061.0115
	27	3,717.0	1,042.7	515,125.62	40,514.29	144,427.97	3,418.6200
ut to insertion second dorsal fin:							
Rica: [2] *M*	29	2,896.5	1,527.6	292,493.79	81,184.30	154,073.13	3,193.3676
19° W.: *L*	21	3,146.2	1,600.1	475,009.34	122,765.07	241,457.31	3,648.6524
29° W.: *L*	44	6,470.7	3,255.9	956,166.11	241,933.41	480,926.32	4,576.1444
39° W.: *L*	46	6,667.6	3,364.6	988,059.18	250,829.34	497,756.66	21,605.0548
49° W.: *L*	112	16,666.4	8,371.8	2,494,141.78	629,133.06	1,252,559.93	14,062.4142
Line Islands:							
	33	3,382.8	1,739.9	349,710.50	92,411.27	179,750.04	2,942.7473
	155	22,517.6	11,248.8	3,268,363.68	819,667.82	1,641,017.17	15,142.9719
Line Islands:							
	43	2,947.9	1,588.1	204,526.51	59,288.09	110,045.93	2,430.8261
	86	8,394.8	4,337.7	830,036.12	221,074.05	428,290.45	10,586.5033
	56	7,732.7	3,868.1	1,073,541.37	268,490.83	536,827.26	5,779.7756
yra Island: [3]							
	34	2,468.9	1,329.1	180,106.01	52,136.85	96,888.92	827.5627
	57	5,379.7	2,796.1	511,367.03	137,936.41	265,548.40	3,627.1688
iix Islands:							
	37	2,503.6	1,347.5	171,117.96	49,464.81	91,972.04	1,712.2044
	59	5,795.3	2,978.1	576,982.99	151,964.35	295,988.89	7,737.1919
	46	6,207.1	3,110.9	841,039.55	211,181.35	421,398.64	3,472.3672
Marshall Islands: *L*	39	5,321.7	2,675.8	728,908.13	184,225.62	366,426.68	2,741.6970
i Island: *S*	31	1,829.9	993.7	109,843.77	32,271.29	59,529.17	1,826.5439
Caroline Islands:							
	59	3,844.2	2,063.0	253,984.88	72,921.12	136,067.49	3,512.4455
	55	5,404.4	2,764.7	539,532.20	140,667.69	275,442.73	8,486.0298
	56	7,837.2	3,881.4	1,103,798.16	270,556.54	546,441.18	6,982.0200
al Caroline Islands:							
	37	2,513.9	1,344.8	173,346.55	49,485.68	92,604.46	2,544.0309
	101	10,183.7	5,180.5	1,038,567.85	268,193.53	527,681.15	11,758.4870
	68	8,997.1	4,472.9	1,194,303.33	295,159.21	593,660.04	3,894.3828
pines (SW. Panay):							
	241	15,711.8	8,908.0	1,036,546.40	332,391.36	586.730.54	12,228.3119
	81	7,349.8	3,996.1	674,621.22	198,764.79	366,077.21	7,713.0714
	28	3,713.5	1,925.6	494,392.59	132,923.10	256,315.20	1,889.6525
: *S*	31	1,789.5	979.4	108,296.33	32,243.84	59,082.02	4,995.994
ii: [2]							
	36	1,884.6	1,041.4	100,518.50	30,637.02	55,486.52	1,859.6900
	34	3,466.4	1,800.3	356,040.12	95,877.41	184,731.92	2,630.4448
	132	19,777.4	9,852.0	2,996,358.30	742,617.26	1,491,512.29	33,134.4306
ii: [3]							
	47	2,679.3	1,463.8	153,111.13	45,690.52	83,635.85	373.9281
ty Islands: *S*	20	2,859.2	1,437.6	409,803.42	103,634.86	206,068.57	1,052.1880
east Africa: *S*	21	1,209.3	665.7	70,745.75	21,367.69	38,872.54	1,107.3458
la, Africa: [4]	46	3,665.0	1,978.2	294,647.00	85,750.74	158,920.80	2,642.1087
	21	2,050.5	1,089.0	206,277.69	57,692.46	109,041.36	6,061.0115
	27	3,717.0	1,892.8	515,125.62	133,489.44	262,208.21	3,418.6200
ut to insertion anal fin:							
Rica: [2] *M*	29	2,896.5	1,709.6	292,493.79	101,685.80	172,442.86	3,193.3676
119° W.: *L*	21	3,146.2	1,766.2	475,009.34	149,575.84	266,533.77	3,648.6524
129° W.: *L*	47	6,895.9	3,825.4	1,016,781.01	312,644.10	563,751.14	5,005.7588
139° W.: *L*	46	6,667.6	3,711.3	988,059.18	305,168.05	549,037.23	21,605.0548
149° W.: *L*	113	16,807.0	9,330.2	2,513,910.14	774,456.74	1,395,190.05	14,129.1754
Line Islands:							
	32	3,285.0	1,869.7	340,145.66	110,060.09	193,454.86	2,919.8788
	153	22,239.8	12,270.3	3,247,595.60	988,185.19	1,791,256.16	14,858.9724
Line Islands:							
	43	2,956.6	1,750.1	205,741.90	71,942.63	121,639.51	2,451.5847
	86	8,405.2	4,786.3	832,220.21	269,255.43	473,284.60	10,738.9654
	56	7,724.0	4,286.3	1,070,968.78	329,570.95	594,058.99	5,608.4943
yra Island: [3]							
	35	2,537.0	1,503.1	184,770.90	64,785.69	109,397.75	845.6475
	57	5,379.7	3,069.5	511,367.03	166,188.61	291,470.97	3,627.1688
nix Islands:							
	36	2,446.3	1,439.9	167,834.67	58,036.31	98,677.17	1,601.7898
	58	5,697.8	3,229.9	567,476.74	181,796.19	321,112.35	7,736.6566
	45	6,078.7	3,350.5	824,552.99	250,453.07	454,396.25	3,428.6858

footnotes at end of table.

TABLE A–3.—*Regression statistics of yellowfin tuna samples*—Continued

Character and size group [1]	*N*	*SX*	*SY*	SX^2	SY^2	*SXY*	S_2
East Marshall Islands: *L*	40	5,453.4	3,002.7	746,253.02	226,261.25	410,890.35	2,763.
Bikini Island: *S*	31	1,829.9	1,094.9	109,843.77	39,177.77	65,588.67	1,826.
East Caroline Islands:							
S	60	3,916.3	2,302.4	259,183.29	89,401.86	152,204.64	3,559.
M	54	5,312.8	2,982.3	531,141.64	166,751.45	297,557.13	8,440.
L	55	7,682.1	4,195.5	1,079,742.15	321,854.99	589,467.25	6,748.
Central Caroline Islands:							
S	37	2,513.9	1,489.0	173,346.55	60,687.04	102,546.64	2,544.
M	102	10,289.2	5,796.7	1,049,698.10	332,230.77	590,407.37	11,780.
L	68	8,977.3	4,940.0	1,189,017.29	360,056.26	654,229.69	3,842.
Philippines (SW. Panay):							
S	242	15,776.4	9,798.3	1,040,719.56	400,472.31	645,393.74	12,228.
M	81	7,349.8	4,391.4	674,621.22	240,101.84	402,363.09	7,713.
L	31	4,109.1	2,351.4	546,703.59	178,857.86	312,602.05	2,035.
Japan: *S*	31	1,789.5	1,071.4	108,296.33	38,581.78	64,628.88	4,995.
Hawaii: [2]							
S	36	1,884.6	1,144.4	100,518.50	36,977.80	60,956.99	1,859.
M	34	3,466.4	1,988.6	356,040.12	117,014.20	204,081.16	2,630.
L	132	19,809.0	10,946.0	3,006,609.34	916,354.34	1,659,647.04	33,908.
Hawaii: [3]							
S	47	2,679.3	1,613.8	153,111.13	55,536.18	92,207.49	373.
L	20	2,859.2	1,599.7	409,803.42	128,289.01	229,277.36	1,052.
Northeast Africa: *S*	47	3,723.5	2,236.5	297,804.75	107,216.25	178,643.00	2,816.
Angola, Africa: [4]							
M	21	2,050.5	1,196.7	206,277.69	69,706.95	119,863.37	6,061.
L	26	3,559.3	1,994.1	490,256.33	153,727.69	274,493.04	3,001.
Y=snout to insertion ventral fin:							
109°–119° W.: *L*	21	3,146.2	885.9	475,009.34	37,666.19	133,726.71	3,648.
119°–129° W.: *L*	47	6,895.9	1,929.5	1,016,781.01	79,629.77	284,429.37	5,005.
129°–139° W.: *L*	46	6,667.6	1,867.5	988,059.18	77,173.33	276,043.66	21,605.
139°–149° W.: *L*	113	16,807.0	4,688.3	2,513,910.14	195,546.89	700,965.38	14,129.
East Line Islands:							
M	31	3,183.1	955.3	329,762.05	29,610.51	98,779.60	2,913.
L	153	22,222.4	6,212.5	3,242,746.86	253,634.17	906,612.53	15,066.
West Line Islands:							
S	42	2,889.5	923.4	201,158.85	20,499.36	64,190.27	2,363.
M	84	8,216.6	2,495.6	814,259.78	74,868.24	246,773.28	10,539.
L	56	7,735.2	2,217.1	1,074,252.62	88,196.69	307,744.22	5,800.
Palmyra Island: [3]							
S	35	2,537.2	799.1	184,770.90	18,312.33	58,159.51	845.
M	57	5,379.7	1,598.4	511,367.03	45,029.14	151,696.73	3,627.
Phoenix Islands:							
S	35	2,383.6	757.8	163,903.38	16,512.26	51,994.83	1,578.
M	56	5,535.9	1,663.0	554,436.73	49,892.82	166,246.01	7,183.
L	46	6,207.1	1,738.5	841,039.55	65,959.63	235,434.15	3,472.
East Marshall Islands: *L*	38	5,180.2	1,434.9	708,885.88	54,390.23	196,334.36	2,715.
Bikini Island: *S*	31	1,829.9	587.3	109,843.77	11,263.09	35,156.10	1,826.
East Caroline Islands:							
S	60	3,916.3	1,216.9	259,183.29	24,959.13	80,411.50	3,559.
M	54	5,311.8	1,546.5	530,957.44	44,777.35	154,125.35	8,453.
L	55	7,685.0	2,136.2	1,080,633.32	83,369.90	300,077.18	6,829.
Central Caroline Islands:							
S	36	2,459.9	771.5	170,430.55	16,747.37	53,398.72	2,344.
M	101	10,204.4	2,979.7	1,042,507.06	88,623.57	303,814.74	11,519.
L	68	8,958.5	2,533.2	1,184,125.53	94,729.64	334,759.16	3,909.
Philippines (SW. Panay):							
S	241	15,702.8	5,088.9	1,035,302.60	108,524.29	335,066.42	12,157.
M	81	7,349.8	2,255.4	674,621.22	63,326.76	206,603.06	7,713.
L	32	4,257.3	1,233.6	568,957.89	47,760.94	164,733.11	2,564.
Japan: S	31	1,789.5	568.9	108,296.33	10,856.57	34,274.53	4,995.
Hawaii: [2]							
S	36	1,884.6	606.9	100,518.50	10,399.99	32,318.81	1,859.
M	34	3,466.4	1,025.2	356,040.12	31,093.84	105,169.90	2,630.
L	133	19,955.4	5,551.6	3,028,042.30	233,905.70	841,363.67	33,922.
Hawaii: [3]							
S	47	2,679.3	870.5	153,111.13	16,161.23	49,734.11	373.
L	20	2,859.2	800.9	409,803.42	32,168.53	114,804.21	1052.
Northeast Africa: S	48	3,805.0	1,217.0	304,447.00	31,064.50	97,190.25	2,821.
Angola, Africa: [4]							
M	21	2,050.5	622.5	206,277.69	18,826.95	62,280.02	6,061.
L	27	3,717.0	1,065.6	215,125.62	42,276.26	147,542.99	3,418.
Y=greatest body depth:							
Costa Rica: [2] *M*	29	2,896.5	737.1	292,493.79	18,981.65	74,476.86	3,193.
109°–119° W.: *L*	21	3,146.2	813.0	475,009.34	31,865.56	122,976.02	3,648.
119°–129° W.: *L*	47	6,895.9	1,729.6	1,016,781.01	64,090.80	255,053.53	5,005.
129°–139° W.: *L*	46	6,667.6	1,673.6	988,059.18	62,388.60	248,086.74	21,605.
139°–149° W.: *L*	109	16,168.8	4,111.2	2,412,075.52	156,425.62	613,937.28	13,634.
East Line Islands:							
M	32	3,278.6	797.7	338,852.86	20,035.94	82,350.48	2,939.
L	154	22,339.4	5,580.4	3,255,028.66	203,481.16	813,560.86	14,452.
West Line Islands:							
S	43	2,947.9	736.8	204,526.51	12,786.92	51,111.30	2,430.
M	83	8,106.1	1,973.0	801,700.31	47,469.79	194,905.57	10,027.
L	57	7,876.2	1,949.6	1,094,133.62	67,274.94	271,142.41	5,809.
Phoenix Islands:							
S	36	2,428.3	602.8	165,447.87	10,182.66	41,030.24	1,652.
M	59	5,795.3	1,422.5	576,982.99	34,800.57	141,587.97	7,737.
L	44	5,943.0	1,478.5	806,235.34	49,956.87	200,558.37	3,527.
East Marshall Islands: *L*	39	5,311.9	1,318.7	727,070.77	44,873.79	180,554.56	2,758.
Bikini Island: *S*	31	1,829.9	453.4	109,843.77	6,729.06	27,179.80	1,826.
East Caroline Islands:							
S	60	3,916.3	974.8	259,183.29	15,994.84	64,346.21	3,559.
M	55	5,404.4	1,295.6	539,532.20	31,008.22	129,299.56	8,486.
L	56	7,837.2	1,949.7	1,103,798.16	68,456.67	274,743.15	6,983.

See footnotes at end of table.

TABLE A-3.—*Regression statistics of yellowfin tuna samples*—Continued

Character and size group [1]	N	SX	SY	SX^2	SY^2	SXY	Sx^2
al Caroline Islands:							
	37	2,513.9	620.5	173,346.55	10,554.85	42,751.50	2,544.0309
	102	10,289.2	2,458.5	1,049,698.10	59,904.61	250,653.30	11,780.0938
: S	71	9,394.9	2,332.8	1,247,581.59	77,105.00	309,934.35	4,424.6040
ii: [2]	30	1,728.2	450.4	104,538.64	7,083.56	27,201.25	4,982.7987
	36	1,884.6	490.7	100,518.50	6,787.50	26,098.06	1,859.6900
	34	3,466.4	874.9	356,040.12	22,676.15	89,801.52	2,630.4448
east Africa: S	132	19,792.5	5,011.4	3,001,505.89	193,468.40	761,486.24	33,755.4639
rtion ventral fin to anterior edge vent:	48	3,805.0	1,006.2	304,447.00	21,317.84	80,536.95	2,821.4792
19° W.: L	17	2,553.6	739.8	387,099.44	32,482.38	112,090.41	3,518.6777
29° W.: L	47	6,895.9	1,954.4	1,016,781.01	81,621.42	287,958.30	5,005.7588
39° W.: L	46	6,667.6	1,891.8	988,059.18	79,521.56	280,216.10	21,605.0548
49° W.: L	112	16,636.5	4,704.8	2,484,839.89	198,883.76	702,735.61	13,651.2091
Line Islands:							
	33	3,382.8	934.7	349,710.50	26,706.59	96,615.03	2,942.7473
Line Islands:	153	22,251.1	6,194.2	3,251,069.35	252,070.96	904,976.23	15,046.7931
	38	2,600.9	734.4	179,843.35	14,337.12	50,761.20	1,825.4340
	83	8,070.3	2,240.3	794,878.69	61,207.59	220,517.27	10,183.0022
	56	7,746.7	2,154.5	1,077,363.37	83,350.01	299,562.14	5,731.9256
nix Islands:							
	19	1,309.2	363.7	90,720.80	7,006.19	25,206.01	510.0295
	49	4,762.2	1,305.9	469,014.30	35,244.71	128,544.55	6,186.7727
	36	4,834.4	1,353.4	651,354.14	51,091.58	182,369.37	2,147.9356
Marshall Islands: L	39	5,321.7	1,479.3	728,908.13	56,402.21	202,694.27	2,741.6970
Caroline Islands:							
	60	3,916.3	1,120.2	259,183.29	21,192.68	74,090.23	3,559.8619
	54	5,319.5	1,487.0	532,324.19	41,555.98	148,692.69	8,304.1854
	55	7,699.4	2,146.7	1,084,809.32	84,431.95	302,578.93	6,977.3135
al Caroline Islands:							
	36	2,438.9	704.0	167,721.55	13,964.26	48,374.98	2,492.8498
	102	10,289.2	2,884.7	1,049,698.10	82,400.69	293,998.80	11,780.0938
	71	9,404.3	2,598.8	1,249,939.11	95,578.08	345,473.82	4,293.2158

TABLE A-3.—*Regression statistics of yellowfin tuna samples*—Continued

Character and size group [1]	Sy^2	Sxy	$\bar{x}$	$\bar{y}$	b	a	s	$\hat{Y}$
: length; Y=head length:								
Rica: [2] M	173.6283	731.3128	99.879	27.238	0.22901	4.365	0.477	27.266
119° W.: L	256.5924	947.8990	149.819	37.952	.25979	.969	.738	35.402
129° W.: L	288.3098	1,137.4179	146.721	37.002	.22722	3.664	.815	35.475
139° W.: L	1,120.4244	4,870.2135	144.948	36.535	.22542	3.861	.716	35.420
149° W.: L	837.5227	3,314.7714	148.713	37.392	.23760	2.059	.677	35.323
Line Islands:								
	141.6873	632.2127	102.509	27.691	.21484	5.668	.435	27.152
	836.7488	3,377.1175	145.319	36.334	.22802	3.198	.660	35.121
Line Islands:								
	164.8874	620.6846	68.707	19.751	.25221	2.422	.451	18.816
	553.6904	2,376.9556	97.758	26.585	.22125	4.956	.575	27.081
	342.1867	1,355.1600	138.179	35.067	.23330	2.830	.688	35.492
yra Island: [3]								
	53.8817	201.4531	72.491	20.877	.23822	3.608	.422	19.092
	173.0948	772.0569	94.381	25.379	.21285	5.290	.399	26.575
nix Islands:								
	102.7173	404.6286	67.665	19.330	.23632	3.339	.450	18.700
	359.7323	1,618.9492	98.225	26.434	.20924	5.881	.607	26.805
	1,103.4174	4,249.3757	133.533	33.470	.25534	−.626	.646	35.122
Marshall Islands: L	171.7190	670.2270	136.335	33.995	.24251	.932	.492	34.883
i Island: S	106.7697	437.7271	59.029	16.803	.23965	2.657	.254	18.646
Caroline Islands:								
	200.9099	838.4362	65.272	18.268	.23552	2.895	.244	18.204
	378.4673	1,779.1837	98.262	25.664	.20966	5.062	.320	26.028
	289.6638	1,281.1993	139.185	34.674	.21355	4.951	.556	34.848
ral Caroline Islands:								
	167.7357	646.6973	67.943	18.889	.25420	1.618	.309	18.141
	564.9781	2,552.7481	100.875	26.211	.21670	4.351	.344	26.021
	290.5322	1,037.7314	132.258	33.152	.25250	−.243	.652	35.107
ppines (SW. Panay):								
	850.8985	3,151.3350	65.192	18.802	.25770	2.002	.402	18.753
	371.8277	1,630.8518	90.738	24.612	.21144	5.426	.584	26.570
	138.9072	485.9244	132.319	33.909	.23255	3.138	.929	35.695
: S	338.5271	1,295.7323	57.726	16.410	.25935	1.439	.292	18.297
ii: [2]								
	134.6856	496.0800	52.350	14.839	.26675	.875	.263	18.214
	134.8224	570.5241	101.953	26.859	.21689	4.746	.588	26.435
	1,772.6468	7,634.8149	150.041	37.064	.22507	3.294	.644	34.804
ii: [3]								
	29.2021	99.5004	57.006	16.232	.26610	1.063	.246	18.360
	84.5580	291.0780	142.960	35.710	.27664	−3.838	.473	34.892
ty Islands: S	69.2153	264.5365	58.147	16.729	.25810	1.721	.250	18.498
heast Africa: S	178.0382	686.5313	79.146	22.319	.24332	3.061	.489	18.877
la, Africa: [4]								
	287.9981	1,310.2386	97.643	26.690	.21617	5.583	.501	27.200
	185.5896	771.5233	137.667	35.604	.22568	4.535	.677	36.130

[1] footnotes at end of table.

TABLE A–3.—*Regression statistics of yellowfin tuna samples*—Continued

Character and size group [1]	Sy^2	Sxy	$\bar{x}$	$\bar{y}$	b	a	s
Y=pectoral fin length:							
Costa Rica: [2] M	134.4011	2.6800	2.9963	26.982	432.27201	−102.540	0.845
109°–119° W.: L	130.2295	1.7719	3.1378	36.095	556.09955	−140.400	1.292
119°–129° W.: L	244.9272	2.2620	3.1658	36.537	514.59869	−126.375	1.709
129°–139° W.: L	909.6983	15.8129	3.1547	35.878	512.96547	−125.947	1.497
139°–149° W.: L	331.2473	4.1885	3.1711	37.311	339.49066	−70.345	1.305
East Line Islands:							
M	416.4364	4.1211	3.1605	36.860	350.85434	−74.028	1.493
L	178.0487	2.9152	3.0083	28.681	532.81670	−131.606	.870
West Line Islands:							
S	221.2870	4.6018	2.8345	20.347	428.28557	−101.051	.768
M	813.2639	12.0643	2.9875	28.117	567.63026	−141.463	1.237
L	216.2000	2.9708	3.1398	36.250	529.81880	−130.103	1.044
Phoenix Islands:							
S	177.6027	3.3268	2.8282	20.322	461.18443	−110.110	.831
M	525.9023	7.8803	2.9878	29.243	546.83293	−134.140	1.3023
L	143.0861	1.7135	3.1292	35.717	496.03404	−119.502	1.149
East Marshall Islands: L	110.7138	1.0990	3.1337	36.038	366.96941	−78.959	1.361
Bikini Island: S	153.2794	3.4868	2.7677	18.026	410.25520	−95.520	.594
East Caroline Islands:							
S	365.2299	7.2406	2.8116	20.652	448.57046	−105.468	.835
M	520.3053	8.3698	2.9884	29.591	544.99401	−133,275	1.122
L	177.7255	2.5316	3.1456	36.791	398.77764	−88.648	1.204
Central Caroline Islands:							
S	301.7364	5.7481	2.8293	21.619	499.91303	−119.746	.650
M	705.1471	11.3351	3.0011	30.641	495.77274	−118.145	1.197
L	183.6188	1.7322	3.1207	35.779	376.72901	−81.787	1.300
Japan: S	534.0737	12.1384	2.7480	17.177	430.92565	−101.241	.627
Hawaii: [2]							
S	215.5789	4.5411	2.7154	15.295	433.19946	−102.336	.745
M	197.1306	2.4781	3.0068	29.129	517.42426	−126.450	1.467
L	927.9426	13.6475	3.1737	37.841	476.97184	−113.536	1.454
Society Islands: S	179.3229	3.0368	2.7570	17.829	556.67987	−135.648	.735
Northeast Africa: S	171.7448	3.4800	2.8962	20.698	407.32721	−97.272	.808
Angola, Africa: [4]							
M	463.4867	7.2230	2.9831	27.133	611.03638	−155.145	1.079
L	143.7067	1.7647	3.1374	35.322	588.40986	−149.286	1.263
Y=height second dorsal fin:							
Costa Rica: [2] M	.256956	.114971	2.9963	2.1899	1.93216	−3.5994	.0366
109°–119° W.: L	.243691	.083607	3.1728	2.5851	2.66332	−5.8651	.0342
119°–129° W.: L	.650678	.143601	3.1646	2.5985	3.29428	−7.8266	.0670
129°–139° W.: L	1.623733	.661222	3.1540	2.5734	2.15071	−4.2099	.0685
139°–149° W.: L	1.205756	.297734	3.1712	2.6373	2.46014	−5.1643	.0651
East Line Islands:							
M	.253147	.087181	3.0069	2.2747	1.71269	−2.8752	.0588
L	1.981966	.420403	3.1610	2.6642	3.00440	−6.8327	.0686
West Line Islands:							
S	.310571	.166120	2.8366	1.9763	1.64155	−2.6801	.0308
M	1.037693	.414389	2.9856	2.2504	2.04152	−3.8448	.0484
L	.738760	.171563	3.1392	2.6188	2.99234	−6.7748	.0640
Phoenix Islands:							
S	.270524	.130046	2.8284	1.9891	1.80376	−3.1127	.0325
M	.497765	.222371	2.9866	2.2771	1.73367	−2.9007	.0460
L	.425878	.106706	3.1275	2.6043	2.67467	−5.7607	.0578
East Marshall Islands: L	.327443	.080457	3.1344	2.6502	2.71759	−5.8678	.0550
Bikini Island: S	.219409	.126190	2.7646	1.8574	1.61455	−2.6062	.0237
East Caroline Islands:							
S	.466530	.263826	2.8116	1.9812	1.63446	−2.6142	.0247
M	.773031	.342603	2.9889	2.3076	2.10777	−3.9923	.0310
L	.442076	.139895	3.1442	2.6805	2.11757	−3.9776	.0530
Central Caroline Islands:							
S	.312898	.184815	2.8272	2.0107	1.63348	−2.6075	.0180
M	1.102133	.472837	3.0011	2.3298	2.06809	−3.8767	.0353
L	.626480	.125078	3.1205	2.6157	2.72033	−5.8731	.0644
Japan: S	.660717	.430861	2.7506	1.8623	1.49317	−2.2448	.0245
Hawaii: [2]							
S	.24851	.15071	2.7153	1.7985	1.44414	−2.1228	.0315
M	.18846	.07539	3.0068	2.2678	1.66645	−2.7427	.0443
L	2.13799	.69805	3.1737	2.6499	2.42564	−5.0484	.0583
Society Islands: S	.202806	.102140	2.7531	1.8640	1.82837	−3.1697	.0299
Northeast Africa: S	.180996	.084192	2.9054	2.0141	1.68539	−2.8826	.0309
Angola, Africa: [4]							
M	.351508	.194019	2.9870	2.2290	1.73044	−2.9398	.0296
L	.168917	.055379	3.1397	2.5297	2.09388	−4.0445	.0470
Y=height anal fin:							
Costa Rica: [2] M	.286182	.120993	2.9964	2.2232	2.00041	−3.7708	.0412
109°–119° W.: L	.328749	.087570	3.1723	2.6176	2.83931	−6.3895	.0667
119°–129° W.: L	.557211	.126487	3.1656	2.6382	2.85608	−6.4030	.0667
129°–139° W.: L	1.689768	.676053	3.1530	2.6213	2.21454	−4.3611	.0677
139°–149° W.: L	1.106309	.264215	3.1705	2.6827	2.200343	−4.2935	.0697
East Line Islands:							
M	.313393	.110760	3.0088	2.3050	2.01323	−3.7524	.0540
L	1.916956	.385379	3.1603	2.7098	2.85648	−6.3175	.0735
West Line Islands:							
S	.343110	.177820	2.8361	1.9814	1.71601	−2.8854	.0308
M	1.566031	.506854	2.9873	2.2942	2.37965	−4.8145	.0651
L	.703209	.162075	3.1388	2.6726	3.17042	−7.2787	.0603
Phoenix Islands:							
S	.338352	.145208	2.8281	1.9862	2.02152	−3.7309	.0358
M	.702531	.272264	2.9884	2.3265	1.83379	−3.1536	.0602
L	.309330	.071908	3.1266	2.6598	2.73654	−5.8963	.0524
East Marshall Islands: L	.263563	.064190	3.1353	2.7137	2.45318	4.9778	.0535
Bikini Island: S	.452704	.224620	2.7712	1.8631	1.90362	−3.4122	.0294

See footnotes at end of table.

TABLE A–3.—*Regression statistics of yellowfin tuna samples*—Continued

Character and size group [1]	Sy^2	Sxy	$\bar{x}$	$\bar{y}$	b	a	s	$\hat{Y}$
aroline Islands:								
	0.647966	0.313363	2.8116	1.9863	1.94135	−3.4720	0.0261	1.9888
	.819340	.350096	2.9889	2.3532	2.15387	−4.0845	.0351	2.3771
	.419122	.141299	3.1427	2.7392	2.22911	−4.2662	.0456	2.7468
l Caroline Islands:								
	.477109	.226364	2.8298	2.0155	1.97398	−3.5705	.0303	1.9821
	1.198853	.484446	3.0020	2.3715	2.19595	−4.2207	.0369	2.3672
	.478073	.109642	3.1202	2.6829	2.44464	−4.9449	.0556	2.7462
S	.804493	.464202	2.7544	1.8535	1.68668	−2.7923	.0277	1.9522
i: [2]								
	.35863	.17991	2.7165	1.7726	1.81452	−3.1565	.0317	1.9476
	.25928	.08162	3.0070	2.3009	1.82473	−3.1861	.0587	2.2881
	2.16105	.70561	3.1737	2.6959	2.45174	−5.0852	.0574	2.6282
y Islands: *S*	.204286	.098154	2.7558	1.8589	1.84795	−3.2337	.0367	1.9644
east Africa: *S*	.255261	.094904	2.9054	2.0478	1.89983	−3.4720	.0427	1.8720
a, Africa: [4]								
	.465751	.229392	2.9831	2.2316	1.94056	−3.5573	.0329	2.2644
	.197757	.058162	3.1374	2.5594	1.82400	−3.1632	.0605	2.5753
t to insertion first dorsal fin:								
Rica: [2] *M*	247.3317	875.6769	99.879	29.445	.27422	2.056	.517	29.478
19° W.: *L*	273.6429	943.5086	149.819	41.229	.25859	2.487	1.249	38.690
29° W.: *L*	297.6080	1,131.6557	146.598	40.557	.23818	5.641	.817	38.986
39° W.: *L*	1,335.2524	5,309.5731	144.948	40.180	.24576	4.558	.831	38.964
49° W.: *L*	1,065.7168	3,687.1724	148.617	40.830	.26423	1.561	.912	38.553
Line Islands:								
	190.5364	726.4491	102.509	29.736	.24686	4.431	.601	29.117
	1,015.4022	3,624.0635	145.412	39.693	.24060	4.707	.968	38.391
Line Islands:								
	193.8216	666.9093	68.684	21.270	.27089	2.664	.560	20.272
	662.5582	2,592.9605	97.701	28.595	2.41917	4.959	.648	29.151
	368.3411	1,357.9180	137.760	37.613	.25409	2.610	.663	38.183
ra Island: [3]								
	68.7829	219.2757	72.491	22.786	.25930	3.989	.601	20.844
	219.5772	861.7644	94.381	27.840	.23758	5.417	.519	29.175
ix Islands:								
	128.3457	438.3757	68.137	21.157	.28120	1.997	.392	20.275
	453.8824	1,834.8211	98.225	28.659	.23714	5.366	.574	29.080
	195.9245	767.8912	134.878	37.111	.22161	7.221	.774	38.246
Marshall Islands: *L*	196.1190	711.5547	136.177	37.472	.26114	1.911	.528	38.471
l Island: *S*	117.0019	455.4545	59.029	19.331	.24935	4.612	.344	20.820
Caroline Islands:								
	225.9424	863.8139	65.445	20.159	.25035	3.775	.412	20.048
	489.4139	2,013.2142	98.262	28.378	.23724	5.066	.472	28.790
	464.1772	1,722.2100	139.950	38.393	.24666	3.873	.854	38.405
al Caroline Islands:								
	173.4274	626.0369	67.963	20.851	.26946	2.538	.336	20.053
	706.3275	2,811.4461	100.875	28.972	.23866	4.897	.595	28.763
	278.6586	999.4995	132.455	36.587	.23281	5.750	.816	38.343
pines (SW. Panay):								
	1,019.2827	3,379.1865	65.192	21.163	.27633	3.148	.597	21.109
	428.3114	1,748.5687	90.738	27.562	.22670	6.992	.636	29.662
	195.0534	625.5600	132.991	37.667	.24373	5.253	1.172	39.375
S	420.2387	1,442.2852	57.726	18.194	.28869	1.529	.365	20.294
i: [2]								
	174.8700	562.9000	52.350	16.717	.30268	.872	.363	20.546
	171.9026	631.9042	101.953	29.859	.24023	5.367	.792	29.390
	2,072.9122	8,073.1400	149.698	41.066	.24585	4.263	.827	38.682
i: [3]								
	36.0749	109.3328	57.006	17.757	.29239	1.089	.302	20.094
	102.3400	308.8700	142.960	39.700	.29355	−2.266	.805	38.831
y Islands: *S*	95.2982	323.5300	57.300	18.191	.28254	2.001	.441	20.366
east Africa: *S*	236.4532	774.5938	79.146	24.656	.27453	2.928	.719	20.772
a, Africa: [4]								
	326.8495	1,389.4743	97.643	28.895	.22925	6.510	.661	29.435
	246.7608	882.9367	137.667	38.619	.25827	3.064	.865	39.222
t to insertion second dorsal fin:								
Rica: [2] *M*	716.6532	1,497.4956	99.879	52.676	.46894	5.839	.731	52.733
19° W.: *L*	845.0696	1,731.8520	149.819	76.195	.47466	5.082	1.101	71.534
29° W.: *L*	1,004.2098	2,109.2262	147.061	73.998	.46092	6.215	.873	70.744
39° W.: *L*	4,730.7931	10,065.2044	144.948	73.143	.46587	5.616	.973	70.838
49° W.: *L*	3,362.0565	6,772.2915	148.807	74.748	.48159	3.084	.956	70.507
Line Islands:								
	676.3607	1,394.4728	102.509	52.724	.47387	4.148	.709	51.535
	3,309.7462	6,849.5643	145.275	72.572	.45233	6.860	1.176	70.186
Line Islands:								
	575.4945	1,172.4419	68.556	36.933	.48232	3.867	.494	35.218
	2,287.5234	4,870.4040	97.614	50.438	.46006	5.530	.747	51.536
	1,308.7299	2,704.8159	138.084	69.073	.46798	4.452	.892	69.969
ra Island: [3]								
	180.7674	376.7145	72.615	39.091	.45521	6.036	.539	35.625
	775.4415	1,650.5199	94.381	49.054	.45504	6.107	.666	51.611
ix Islands:								
	390.3168	793.6346	67.665	36.419	.46352	5.054	.801	35.183
	1,640.9668	3,463.7556	98.225	50.476	.44768	6.503	1.259	51.271
	796.5933	1,623.2620	134.937	67.628	.46748	4.548	.926	69.995
Marshall Islands: *L*	638.2959	1,303.4785	136.454	68.610	.47543	3.736	.709	70.296
Island: *S*	418.3968	872.0206	59.029	32.058	.47742	3.876	.268	34.908
Caroline Islands:								
	786.0523	1,650.8019	65.156	34.966	.46999	4.343	.423	34.892
	1,693.7611	3,778.2813	98.262	50.267	.44524	6.517	.466	51.041
	1,533.9336	3,239.2500	139.950	69.311	.46394	4.383	.759	69.335

footnotes at end of table.

TABLE A-3.—*Regression statistics of yellowfin tuna samples*—Continued

Character and size group [1]	Sy^2	Sxy	$\bar{x}$	$\bar{y}$	b	a	s
Central Caroline Islands:							
S	607.6519	1,234.3865	67.943	36.346	0.48521	3.379	0.499
M	2,474.9137	5,338.0030	100.829	51.292	.45397	5.519	.722
L	941.0570	1,849.3255	132.310	65.778	.47487	2.948	.976
Philippines (SW. Panay):							
S	3,128.0239	5,980.6878	65.194	36.963	.48909	5.077	.921
M	1,618.9233	3,478.0029	90.738	49.335	.45092	8.419	.801
L	496.8372	932.5000	132.625	68.771	.49348	3.323	1.283
Japan: *S*	1,301.1187	2,545.3652	57.726	31.594	.50914	2.203	.422
Hawaii: [2]							
S	511.6323	969.2300	52.350	28.928	.52118	1.644	.437
M	551.5250	1,186.0400	101.953	52.950	.45089	6.980	.724
L	7,299.8055	15,399.0719	149.829	74.636	.46475	5.003	1.049
Hawaii: [3]							
S	100.9362	189.9066	57.006	31.145	.50787	2.193	.316
L	300.1720	549.2740	142.960	71.880	.52203	−2.749	.864
Society Islands: *S*	265.0000	537.7300	57.586	31.700	.48560	3.736	.452
Northeast Africa: *S*	679.5392	1,309.8653	79.549	42.879	.49576	3.442	.828
Angola, Africa: [4]							
M	1,220.0315	2,708.2886	97.643	51.857	.44684	8.226	.720
L	797.1497	1,632.7434	137.667	70.104	.47760	4.354	.833
Y=snout to insertion anal fin:							
Costa Rica: [2] *M*	901.9325	1,689.1911	99.879	58.952	.52897	6.119	.558
109°–119° W.: *L*	1,030.0096	1,923.3681	149.819	84.105	.52714	5.129	.921
119°–129° W.: *L*	1,289.0966	2,483.5686	146.721	81.391	.49614	8.597	1.124
129°–139° W.: *L*	5,738.7524	11,092.3631	144.948	80.680	.51342	6.261	.997
139°–149° W.: *L*	4,079.4653	7,467.2943	148.773	82.568	.52850	3.941	1.095
East Line Islands:							
M	817.0247	1,518.4694	102.656	58.428	.52005	5.042	.955
L	4,131.1894	7,667.8075	145.358	80.998	.51604	5.987	1.074
West Line Islands:							
S	713.5600	1,305.8900	68.758	40.700	.53267	4.075	.662
M	2,875.5732	5,496.1261	97.735	55.655	.51179	5.635	.864
L	1,492.9556	2,855.7543	137.929	76.541	.50918	6.311	.848
Palmyra Island: [3]							
S	233.9869	435.8838	72.491	42.946	.51544	5.581	.531
M	903.3425	1,769.4060	94.381	53.851	.48782	7.810	.855
Phoenix Islands:							
S	444.3098	831.9653	67.953	39.997	.51940	4.702	.599
M	1,929.7416	3,813.6566	98.238	55.688	.49293	7.264	.944
L	989.7312	1,803.2645	135.082	74.456	.52593	3.412	.981
East Marshall Islands: *L*	856.0678	1,517.2455	136.335	75.068	.54898	.223	.780
Bikini Island: *S*	506.6084	957.7826	59.029	35.290	.52437	4.337	.388
East Caroline Islands:							
S	1,051.0974	1,923.1547	65.272	38.373	.54023	3.111	.458
M	2,045.6484	4,142.9923	98.385	55.228	.49083	6.938	.483
L	1,814.6219	3,462.6946	139.675	76.282	.51312	4.612	.845
Central Caroline Islands:							
S	764.8509	1,379.1509	67.943	40.243	.54211	3.410	.701
M	2,802.0358	5,668.0991	100.875	56.830	.48116	8.293	.865
L	1,179.7895	2,055.2489	132.019	72.647	.53493	2.026	1.104
Philippines (SW. Panay):							
S	3,750.4799	6,625.5577	65.192	40.489	.54181	5.167	.818
M	2,022.9023	3,895.0441	90.738	54.215	.50499	8.393	.842
L	500.3775	920.1875	132.552	75.852	.45201	15.937	1.706
Japan: *S*	1,552.8136	2,781.4510	57.726	34.561	.55674	2.423	.384
Hawaii: [2]							
S	598.5956	1,047.6500	52.350	31.789	.56335	2.298	.497
M	704.4953	1,337.5412	101.953	58.488	.50848	6.647	.873
L	8,665.5824	17,000.7218	150.068	82.924	.50137	7.684	1.045
Hawaii: [3]							
S	124.4687	210.5892	57.006	34.337	.56318	2.232	.361
L	337.0055	584.2480	142.960	79.985	.55527	.604	.836
Northeast Africa: *S*	792.1596	1,459.8564	79.098	47.460	.51834	6.460	.888
Angola, Africa: [4]							
M	1,512.1458	3,014.1629	7.643	56.986	.49730	8.428	.834
L	787.8897	1,508.4197	136.893	76.696	.50250	7.907	1.116
Y=snout to insertion ventral fin:							
109°–119° W.: *L*	293.8657	1,002.0157	149.819	42.186	.27463	1.041	.992
119°–129° W.: *L*	417.6371	1,330.6669	146.721	41.053	.26583	2.051	1.192
129°–139° W.: *L*	1,356.8898	5,353.5948	144.948	40.598	.24779	4.681	.830
139°–149° W.: *L*	1,032.2273	3,653.3615	148.773	41.489	.25857	3.021	.888
East Line Islands:							
M	171.8619	688.7797	102.681	30.816	.23594	6.589	.568
L	1,378.2468	4,281.4189	145.244	40.605	.28416	−.668	1.035
West Line Islands:							
S	197.7514	662.5486	68.798	21.986	.27978	2.738	.556
M	725.1524	2,662.0067	97.817	29.710	.25258	5.003	.802
L	419.3256	1,499.3643	138.129	39.591	.25849	3.886	.767
Palmyra Island: [3]							
S	67.7354	231.6094	72.491	22.831	.27388	2.977	.361
M	206.6390	838.6164	94.381	28.042	.23120	6.221	.481
Phoenix Islands:							
S	104.8074	386.4849	68.103	21.651	.24564	4.922	.547
M	507.6593	1,849.5511	98.855	29.696	.25748	4.243	.763
L	255.6681	846.2511	134.937	37.793	.24371	4.908	1.060
East Marshall Islands: *L*	207.6508	727.2816	136.321	37.760	.26782	1.250	.598
Bikini Island: *S*	136.5968	488.3494	59.029	18.945	.26736	3.163	.456
East Caroline Islands:							
S	278.3699	982.4089	65.272	20.282	.27597	2.269	.354
M	487.3084	2,001.3000	98.367	28.639	.23674	5.352	.510
L	399.8920	1,591.7800	139.727	38.840	.23308	6.272	.738

See footnotes at end of table.

TABLE A–3.—*Regression statistics of yellowfin tuna samples*—Continued

Character and size group [1]	Sy^2	Sxy	$\bar{x}$	$\bar{y}$	b	a	s	$\hat{Y}$
Caroline Islands:								
	213.6964	681.6964	68.331	21.431	0.29080	1.560	0.674	20.462
	716.5196	2,764.7333	101.034	29.502	.24001	5.253	.731	29.254
	360.4895	1,028.6865	131.743	37.253	.26316	2.584	1.166	39.426
nes (SW. Panay):								
	1,068.2601	3,489.7440	65.157	21.116	.28704	2.413	.528	21.071
	526.4000	1,951.9623	90.738	27.844	.25307	4.881	.641	30.188
S	205.6600	614.1950	133.041	38.550	.23954	6.681	1.397	40.217
[2]	416.3374	1,434.3187	57.726	18.352	.28709	1.779	.396	20.440
	168.6675	547.5950	52.350	16.858	.29445	1.444	.467	20.583
	181.0448	647.7448	101.953	30.153	.24625	5.047	.820	29.672
	2,174.4026	8,398.2667	150.041	41.741	.24758	4.594	.852	39.255
[3]								
	38.4587	110.0536	57.006	18.521	.29432	1.743	.367	20.874
	96.4895	307.5460	142.960	40.045	.29229	−1.741	.605	39.180
st Africa: *S*	208.4792	717.6459	79.146	25.229	.25435	5.098	.751	21.631
Africa: [4]								
	374.2714	1,497.3414	97.643	29.643	.24704	5.521	.479	30.225
	220.5800	845.3900	137.667	39.467	.24729	5.423	.679	40.044
st body depth:								
ica: [2] *M*	246.6014	855.8203	99.879	25.417	.26800	−1.351	.799	25.449
° W.: *L*	390.8457	1,173.1343	149.819	38.714	.32153	−9.457	.848	35.557
° W.: *L*	441.5200	1,284.4100	146.721	36.800	.25659	−.847	1.577	35.076
° W.: *L*	1,498.6661	5,502.0583	144.948	36.383	.25467	−.530	1.488	35.124
° W.: *L*	1,361.7169	4,091.6786	148.338	37.717	.30010	−6.799	1.118	35.215
ne Islands:								
	150.7747	621.1294	102.456	24.928	.21128	3.281	.807	24.409
	1,267.7564	4,062.2382	145.061	36.236	.28108	−4.538	.910	34.813
ine Islands:								
	161.9377	599.3763	68.556	17.135	.24657	.231	.587	16.258
	569.4407	2,214.7833	97.664	23.771	.22087	2.200	.995	24.287
	591.7793	1,748.7343	138.179	34.204	.30106	−7.396	1.090	34.752
Islands:								
	89.1089	369.7056	67.453	16.744	.22375	1.651	.433	16.195
	503.8539	1,862.3048	98.225	24.110	.24070	.467	.988	24.537
	275.9098	860.0632	135.068	33.602	.24398	.648	1.254	34.805
arshall Islands: *L*	284.8236	842.8003	136.279	33.813	.30548	−7.818	.860	34.949
sland: *S*	97.7194	416.0368	59.029	14.626	.22777	1.181	.319	15.986
roline Islands:								
	157.5893	719.3893	65.272	16.247	.20208	3.057	.459	16.192
	488.5953	1,991.5484	98.262	23.556	.23469	.495	.632	23.964
	575.7756	1,882.6350	139.950	34.816	.26964	−2.920	1.123	34.830
Caroline Islands:								
	148.8973	592.7176	67.943	16.770	.23298	.941	.556	16.085
	647.5291	2,653.3177	100.875	24.103	.22524	1.382	.706	23.906
	457.7347	1,252.3399	132.323	32.856	.28304	−4.597	1.223	35.020
S	321.5547	1,255.2073	57.607	15.013	.25191	.501	.437	16.875
[2]								
	98.9864	409.9150	52.350	13.631	.22042	2.092	.504	16.419
	162.8941	602.8918	101.953	25.732	.22920	2.364	.879	25.284
	3,209.8397	10,060.9787	149.943	37.965	.29805	−6.726	1.274	35.001
st Africa: *S*	225.3725	774.6375	79.146	20.837	.27455	−.893	.525	16.953
ion ventral fin to anterior edge vent:								
° W.: *L*	288.0247	963.7465	150.212	43.518	.27389	2.376	1.267	40.721
° W.: *L*	351.6464	1,206.2371	146.721	41.583	.24097	6.228	1.164	39.964
° W.: *L*	1,719.2287	6,003.8027	144.948	41.126	.27776	.865	1.075	39.751
° W.: *L*	1,248.5543	3,883.7779	148.540	42.007	.28450	−.253	1.143	39.577
ne Islands:								
	231.9206	799.7827	102.509	28.324	.27178	.464	.685	27.642
	1,298.9754	4,141.1737	145.432	40.485	.27522	.459	1.027	38.990
ine Islands:								
	143.8737	495.3853	68.445	19.326	.27138	.751	.512	18.391
	738.3841	2,687.2328	97.233	26.992	.26389	1.333	.601	27.722
	459.4699	1,521.6909	138.334	38.473	.26548	1.748	1.014	38.915
x Islands:								
	44.2063	145.1658	68.905	19.142	.28462	−.470	.412	18.030
	441.1425	1,627.0607	97.188	26.651	.26299	1.092	.531	27.391
	211.2589	622.7878	134.289	37.594	.28995	−1.343	.950	39.250
arshall Islands: *L*	291.2231	838.0954	136.454	37.931	.30568	−3.780	.973	39.015
roline Islands:								
	278.5460	972.9090	65.272	18.670	.27330	.831	.467	18.596
	608.4060	2,209.4215	98.509	27.537	.26606	1.328	.629	27.934
	644.2975	2,064.3486	139.989	39.031	.29587	−2.388	.795	39.034
Caroline Islands:								
	197.1489	680.9356	67.747	19.556	.27316	1.050	.573	18.805
	817.7146	3,006.1016	100.875	28.281	.25518	2.540	.709	28.058
	454.6795	1,249.9491	132.455	36.603	.29115	−1.961	1.147	38.800

mall, less than 80 cm., compared at length of 65 cm.; *M*, medium, 80 to 120 cm., compared at length of 100 cm.; *L*, large, over 120 cm., compared of 140 cm.

[2] Schaefer (1952). [3] Godsil and Greenhood (1951). [4] Schaefer and Walford (1950).

23. Climatic Oceanography and its Application to the Hawaiian Skipjack Fishery

There are changes in the temperature and salinity of the ocean's waters which are analogous to changes in temperature and humidity in the atmosphere. Just as the latter can be explained in terms of movement of air masses, weather fronts, and circulatory systems, so the analogous changes in the ocean can be related to the movements of fronts which separate different water types or water masses. The boundary between the North Pacific Central water and the California Current Extension water moves seasonally through the region of the Hawaiian Islands. The time or northward movement of the boundary in late winter, as reflected in the time of initial warming of the sea near Oahu, and the presence of California Current Extension water around the Islands during the summer months have been shown to be related to the success of the Hawaiian skipjack fishery. Consequently, the time of initial warming early in the spring can be used to predict the relative success of the summer skipjack fishery.

GUNTER R. SECKEL
U. S. Bureau of Commercial Fisheries

1964. /Abstract/ Proceedings of the Hawaiian Academy of Science. 39th Annual Meeting, 1963-1964, p. 26.

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PONTELLID COPEPOD OCCURRENCE IN THE CENTRAL SOUTH PACIFIC

BY KENNETH SHERMAN

PONTELLID COPEPOD OCCURRENCE IN THE CENTRAL SOUTH PACIFIC

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ABSTRACT

The distribution of pontellid copepods collected in the central South Pacific from January to April 1962 was examined for associations with hydrographic features, particularly water temperature and salinity. Of the 15 species of adult forms collected, 5 were found in all but one case within 40 km of islands and are considered to be associated with neritic waters. These were *Labidocera acuta, L. bataviae, L. pavo, Pontella denticauda,* and *Pontellopsis macronyx.* Five other species, *Pontella princeps, P. tenuiremis, P. securifer, Pontellopsis armata,* and *P. regalis,* revealed no association with temperature or salinity within the range of values encountered for those properties, but occurred throughout the area surveyed. *Pontellina plumata* appeared to be affected by temperature changes, favoring waters warmer than 26.0C. Of the remaining four species, the numbers of *Labidocera acutifrons, L. detruncata,* and *Pontellopsis villosa,* were reduced where the salinity was less than 34.5‰, while *Pontella fera* was found to be numerous in waters with salinity lower than 34.5‰.

INTRODUCTION

Previous investigations have shown that pontellid copepods are more abundant at the surface than in deeper levels in waters of the central Pacific (Wilson 1942; Heinrich 1960; Sherman 1963). The possibility of using pontellids as indicators of surface water movements in the Hawaiian Islands region was suggested earlier (Sherman 1963). The present study is concerned with the relationships between pontellid distribution and surface water characteristics, particularly salinity and temperature, in the region extending south and west of the Hawaiian Islands to New Caledonia and Samoa.

The study is based on 60 surface plankton samples taken by personnel of the U.S. Bureau of Commercial Fisheries Biological Laboratory, Honolulu, during Cruise 55 of the Bureau's research vessel *Charles H. Gilbert,* January to April 1962 (Fig. 1A).

Little is known of pontellid distribution in the central Pacific. Heinrich (1960, p. 45) reported that the occurrence in large numbers of several pontellids was "limited by the influence of the salinity factor." The abundant occurrence of the species *Pontellopsis villosa, Labidocera acutifrons, Pontella tenuiremis,* and *Pontellina plumata* was limited to waters with salinities greater than 35‰. *Pontella fera* was found "almost exclusively" in an area of low salinity (less than 35‰). Heinrich's samples were collected from transects made along longitudes 172° E and 174° W, between latitudes 30° N and 41° S, from November 1957 to February 1958.

Additional pontellid occurrence data for the Pacific is provided in the plankton lists and taxonomic works of Dana (1853), Brady (1883), Giesbrecht (1892), Cleve (1901), Scott (1909), Farran (1936), Dakin and Colefax (1940), Wilson (1942, 1950), Sewell (1948), and Grice (1961).

METHODS

All tows were made at the surface using a 1-meter net with mesh openings of 0.66 mm in the body section and 0.31 mm in the cod end. An Atlas flowmeter suspended in the mouth opening of the net recorded the amount of water strained. The duration of tow was approximately 30 min.

All pontellids in the total or an aliquot of the sample were removed and sorted by species, and the number of each species per 1,000 m^3 of water strained was calculated. Temperature-salinity-plankton projections were constructed for each species using the technique of Bary (1959) to de-

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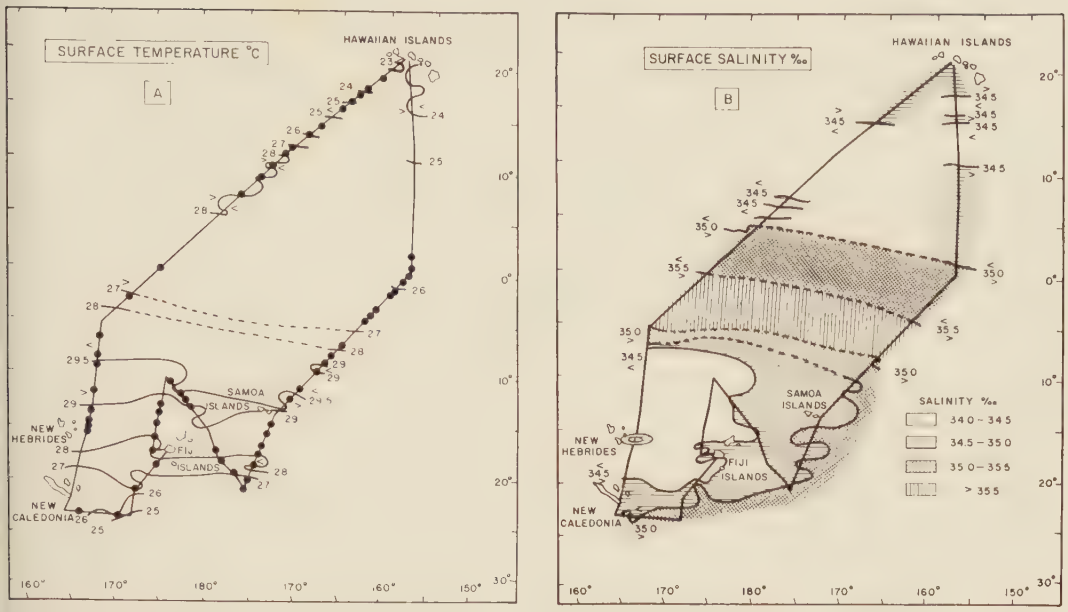


FIG. 1. Vessel track, surface plankton station positions, and temperatures (A) and surface salinites (B), *Charles H. Gilbert* Cruise 55, January–April 1962.

termine the relations between pontellids and surface hydrographic conditions. Identification of pontellids was facilitated by reference to the taxonomic works of Giesbrecht (1892), Scott (1909), Sewell (1929), and Wilson (1950).

COMPOSITION OF SAMPLES

In the collections, there were 15 species of pontellids represented by adult forms that could be identified. These were *Labidocera acuta* (Dana), *L. acutifrons* (Dana), *L. bataviae* Scott, *L. detruncata* (Dana), *L. pavo* Giesbrecht, *Pontella denticauda* Scott, *P. fera* Dana, *P. princeps* Dana, *P. securifer* Brady, *P. tenuiremis* Giesbrecht, *Pontellopsis armata* (Giesbrecht), *P. macronyx* Scott, *P. regalis* (Dana), *P. villosa* Brady, and *Pontellina plumata* (Dana).

Two groups of pontellids were found that could not be identified from published taxonomic reports. One, a *Pontella* sp., appeared to be closely related to *P. tenuiremis* and *P. fera*; another, a *Pontellopsis* sp., was similar to published descriptions of female *P. macronyx*.

There were immature representatives of the genera *Labidocera, Pontella,* and *Pontellopsis* for which it was not possible to make specific identification. These forms may have been single species or mixtures and were not used in attempts to relate distribution to water qualities.

RELATIVE ABUNDANCE

Relative abundance of pontellid copepods, expressed as percentage of total numbers present per 1,000 m^3 of water strained, varied among species. Immature forms of *Labidocera* sp. were the most abundant (38% of the total). Other categories of immature pontellids distinguished were *Pontella* sp. (3%) and *Pontellopsis* sp. (1%). Of the adult forms, *Labidocera detruncata* (24%), *L. acutifrons* (13%), *Pontellina plumata* (10%), and *Pontella fera* (4%) were most numerous. The adults of *Pontella tenuiremis, P. denticauda, Pontellopsis villosa, P. regalis,* and *P. armata* were less numerous (2–1% of the total). The remaining species, *Pontella securifer, P. princeps, Pontellopsis macronyx, Labidocera bataviae, L. pavo,* and *L. acuta,* were

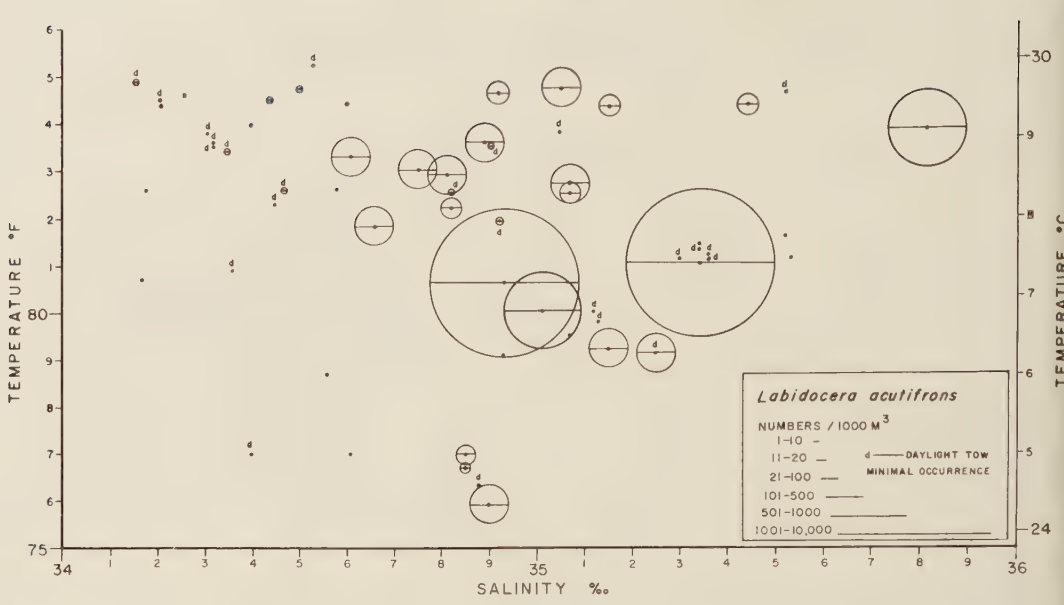


FIG. 2. Temperature-salinity-pontellid relation of *Labidocera acutifrons*. Symbols indicate ranges of pontellid abundance in numbers per 1,000 m^3 of water strained. Letter *d* represents tows taken during daylight hours, indicating minimal occurrence.

rare, each comprising less than 1% of the adults.

RELATION TO SURFACE TEMPERATURE AND SALINITY

Surface temperature and salinity distributions (Figs. 1A and B) were based on observations taken every 3 hr during the cruise. The temperature range was 5.7C, from 23.8C in the northern region to 29.5C in the vicinity of Samoa. Salinity ranged from 33.33‰ at the New Hebrides to 35.85‰ near 5° N lat, 162° W long.

Hydrographic data were inadequate to construct temperature-salinity curves for the surface waters from which my samples were collected. In the absence of accepted definitions of the surface water types in the area sampled, and in recognition of the clumped distribution[2] of pontellids, the temperature and salinity ranges within which the greatest numbers of each pontellid species occurred were estimated by inspection. Differences among the distributions of pontellids and surface salinity or temperature were thought to reflect environmental changes. However, the specific factor or group of factors limiting pontellid distribution has not been determined. For those species for which day–night differences in occurrence have been reported (Sherman 1963), a symbol has been used on the *T-S-P* projection to denote the time of expected minimal numbers.

The *T-S-P* relations of the four most numerous (> 4% of the total number present) species, *Labidocera acutifrons*, *L. detruncata*, *Pontellina plumata*, and *Pontella fera*, are shown in Figs. 2–5, respectively. Included for comparison is the less numerous *Pontellopsis villosa*, plotted with *Pontella fera* in Fig. 5.

Of the two variables measured, salinity appeared more important in limiting the distribution of *Labidocera acutifrons*. This species was found in aggregations of 100 per 1,000 m^3 or more over a wide temperature range (24.6–29.3C), with no apparent concentration at any temperature. In contrast, there was a sharp reduction in num-

[2] This clumped distribution is evident in the occasional occurrence of low numbers of pontellids at stations located in areas of high pontellid concentration.

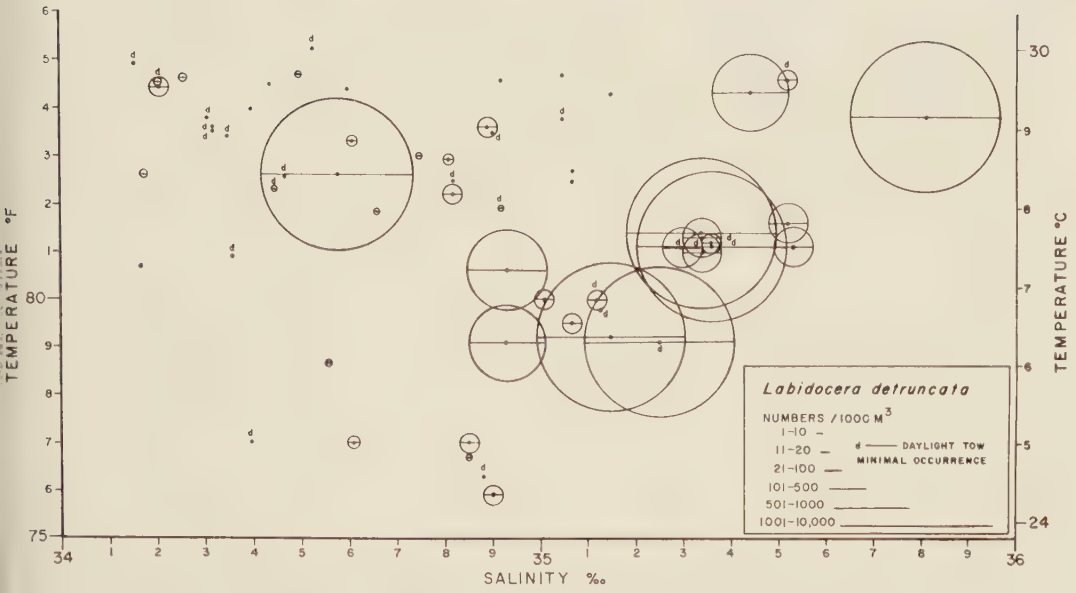


FIG. 3. Temperature-salinity-pontellid relation of *Labidocera detruncata*. Symbols as in Fig. 2. Letter *d* represents tows taken during daylight hours, indicating minimal occurrence.

bers of *L. acutifrons* from stations where salinity values were > 34.6‰ (100 to more than 1,000 per 1,000 m³), to stations where salinities were < 34.4‰ (10 or less per 1,000 m³) (Fig. 2). In view of this sharp reduction, the 34.5‰ isohaline was selected to distinguish between low- and high-salinity water. *L. detruncata* was also found in numbers greater than 1,000 per 1,000 m³ in salinities > 34.5‰, but the reduction in numbers in waters of less than 34.5‰ salinity was less pronounced than

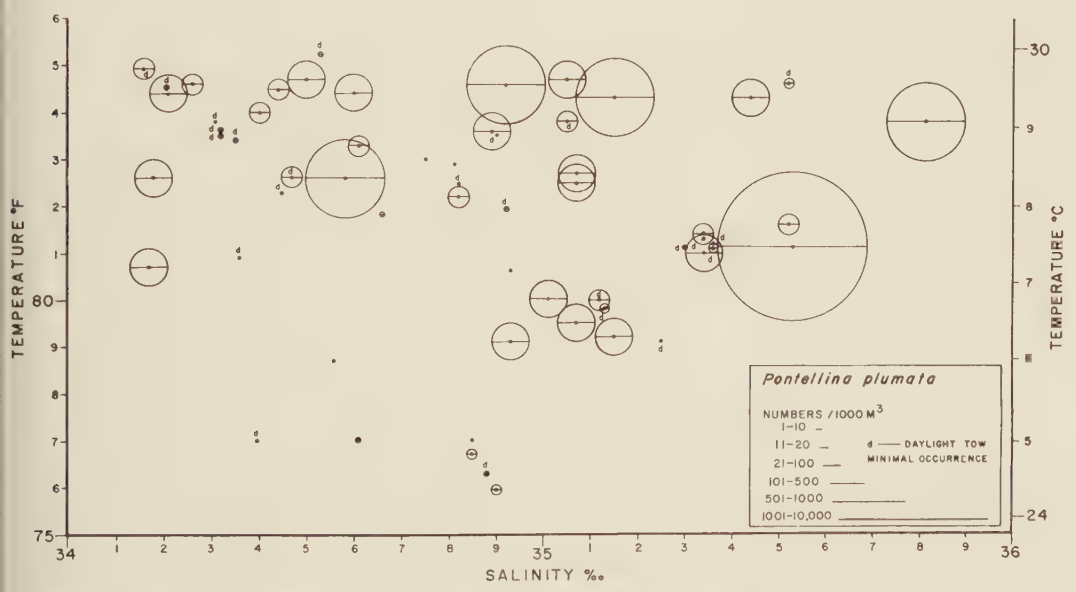


FIG. 4. Temperature-salinity-pontellid relation of *Pontellina plumata*. Symbols as in Fig. 2. Letter *d* represents tows taken during daylight hours, indicating minimal occurrence.

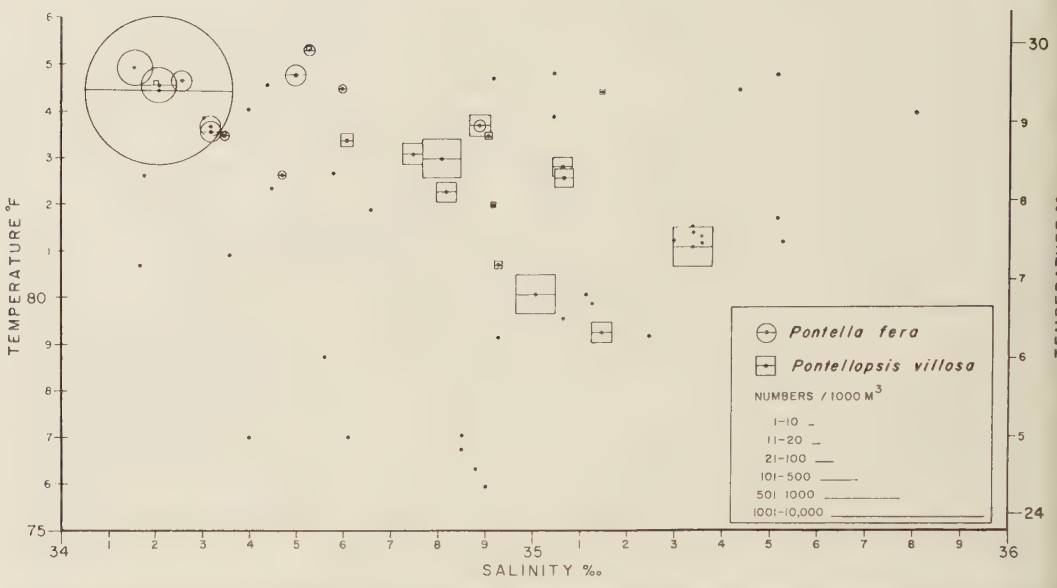


FIG. 5. Temperature-salinity-pontellid relation of *Pontella fera* and *Pontellopsis villosa*. Symbols as in Fig. 2.

for *L. acutifrons*. Generally, fewer than 20 per 1,000 m^3 occurred at a station, except at one station in low-salinity water, at which 79 per 1,000 m^3 were present (Fig. 3). In addition to salinity, temperatures cooler than 26.0C, where less than 100 per 1,000 m^3 occurred, appeared to limit the distribution of *L. detruncata*.

Pontellina plumata occurred in concentrations exceeding 100 per 1,000 m^3 throughout a wide range of salinity (34.1‰–35.8‰), with no abrupt reduction in low-salinity waters except for 10 or fewer per 1,000 m^3 found at several stations located in salinities less than 34.4‰; however, these values were determined from samples collected during daylight and therefore represent minimal estimates of occurrence (Fig. 4). In relation to temperature, *P. plumata* was found to be less numerous (< 20 per 1,000 m^3) in waters cooler than 26.0C.

Pontella fera was most numerous, up to 2,200 per 1,000 m^3, in low-salinity, warm (> 28.5C) waters. Its occurrence in high-salinity water (>34.5‰) was limited to three stations where less than 18 per 1,000 m^3 were found. In contrast, *Pontellopsis villosa* was more numerous (up to 160 per 1,000 m^3) in higher salinity (> 34.5‰), cooler (< 28.5C) waters (Fig. 5).

The contrasting occurrence in relation to temperature and salinity of *Pontella fera* and *Pontellopsis villosa* suggests that these species are associated with two distinct surface waters of different origin and that the two waters mixed to a degree, as evidenced by the low numbers (< 18 per 1,000 m^3) of *P. villosa* found at several stations in low-salinity water and of *Pontella fera* in high-salinity water. The absence of large numbers of *Labidocera acutifrons* and *L. detruncata* in low-salinity waters also suggests that these waters are distinct in origin.

The less abundant species (< 4% of the total), *Pontella tenuiremis*, *P. securifer*, *P. princeps*, *Pontellopsis armata*, and *P. regalis*, were all widely distributed. The remaining rarely occurring pontellids (< 1% of the total), *Pontella denticauda*, *Pontellopsis macronyx*, *Labidocera acuta*, *L. bataviae*, and *L. pavo*, were found at only a few stations and were in insufficient numbers for reliable *T-S-P* estimates. However, all of them were collected within approximately 40 km of islands, except two *Pontellopsis*

TABLE 1. *Station number, distance from nearest land, and approximate depth of locations at which* Pontella denticauda, Pontellopsis macronyx, Labidocera acuta, Labidocera bataviae, *and* Labidocera pavo *were collected**

Station	Species	Approximate distance from nearest island (km)	Approximate depth over which collections were made (m)
30	*Labidocera pavo*	25 (Mitre Island, New Hebrides)	2,700–4,500
35	*Pontella denticauda* *Labidocera acuta* *Labidocera bataviae*	30 (Ambrim Island, New Hebrides)	2,700
36	*Pontella denticauda* *Pontellopsis macronyx* *Labidocera acuta* *Labidocera bataviae*	10 (Epi Island, New Hebrides)	900
53	*Pontella denticauda*	40 (Kandavu Island, Fiji)	2,700
74	*Labidocera pavo*	28 (Rotuma, Fiji)	2,700–4,500
85	*Pontella denticauda* *Labidocera pavo*	25 (Lau Group, Fiji)	2,700
86	*Pontella denticauda*	20 (Tongatabu Group, Tonga)	1,800
89	*Labidocera pavo* *Pontellopsis macronyx*	20 (Eua Island, Tonga)	2,700
99	*Pontellopsis macronyx*	75 (Tutuila Island, Samoa)	4,500–6,400
102	*Labidocera bataviae*	10 (Tutuila Island, Samoa)	2,700

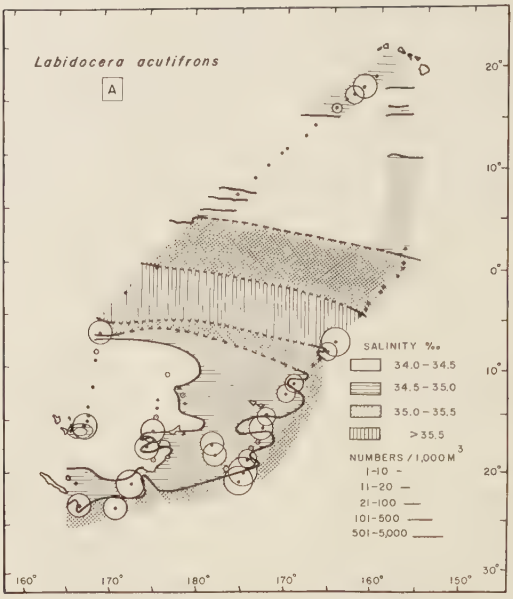
* Bathymetry data from U.S. Navy Hydrographic Office Chart, H. O. Misc. 15, 254, 2nd ed., October 1961.

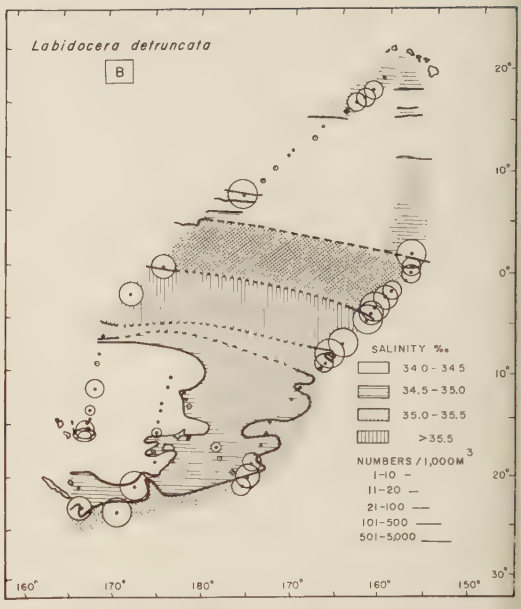
macronyx found at Station 99, 75 km from the nearest land area (Table 1). It appears that these species are more closely related to island influences than to temperature and salinity values. This apparent island association is in agreement with the findings of Sewell (1948, p. 323–324), who included *Pontella denticauda, Pontellopsis macronyx, Labidocera acuta, L. bataviae,* and *L. pavo* in a listing of Indian Ocean calanoids classified as "essentially littoral in character." In addition, Scott (1909) reported all of these species but *L. pavo* from the Malay Archipelago, including the type specimens of *Pontella denticauda, Pontellopsis macronyx,* and *Labidocera bataviae.*

DISCUSSION

The distributions in relation to surface salinity of *Labidocera acutifrons, L. detruncata, Pontellopsis villosa,* and *Pontella fera* (Fig. 6A–C) show a break in the distribution of these species near (within approximately 10 km of) the 34.5‰ isohaline (north and west of New Caledonia and Fiji), where there was a decrease in numbers of *Labidocera acutifrons, L. detruncata,* and *Pontellopsis villosa.* North of the equator, the break at the 34.5‰ isohaline was more pronounced for those species present, with *Labidocera acutifrons* absent from waters of less than 34.5‰ salinity and *L. detruncata* reduced from 100 per 1,000 m^3 at several locations in high-salinity water ($> 34.5‰$) to 10 per 1,000 m^3 or less in low-salinity water.

Near the Hawaiian Islands, salinities of 34.5‰ have been reported to represent the northern boundary region of the North Pacific Equatorial Water type (Sherman 1963). Several pontellids, including *L. acutifrons* and *L. detruncata,* decreased markedly from a region of abundance to the north in the high-salinity ($> 34.9‰$) North Pacific Central Water type to absence of the former species and to low numbers of the latter near the 34.5‰ isohaline. Although *Pontellopsis villosa* was not found in the central North Pacific, Heinrich (1960) reported it present in waters with salinities greater than 35.0‰ from latitudes 30° N to 20° N and 10° S to 30° S along longitudes 174° W and 172° E, and absent from waters with salinities lower than 35.0‰ between latitudes 20° N to 10° S. This association of *P. villosa* with high-salinity water generally agrees with the present findings; however, in our material





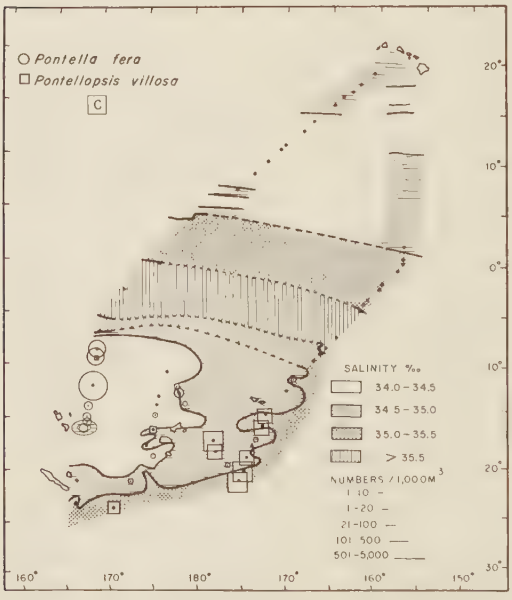


FIG. 6. Horizontal distribution of (A) *Labidocera acutifrons*, (B) *Labidocera detruncata*, and (C) *Pontella fera* and *Pontellopsis villosa*, in relation to surface salinity, *Charles H. Gilbert* Cruise 55, January–April 1962. Symbols as in Fig. 2.

the lower limit of *P. villosa* abundance was at 34.5‰. The smaller numbers of the forms associated with high-salinity, *Labidocera acutifrons, L. detruncata*, and *Pontellopsis villosa*, and of the form associated with low-salinity, *Pontella fera*, in waters of 34.5‰ salinity, suggest that this isohaline is a faunal and a hydrographic boundary.

On the other hand, in a recent study of surface plankton of the Indian Ocean, Voronina (1962) found that the distributions of *Pontellopsis villosa, Pontella fera, Labidocera detruncata*, and other pontellids were more closely related to current systems than to specific salinity or temperature values. However, it is difficult to compare the distributions found by Voronina with the present ones, because Voronina used the percentage composition of the total numbers of pontellids in surface trawl collections in which the amount of water strained could not be determined.

Rochford (1959, p. 19, Pl. 2) has indicated the presence of a hydrographic boundary in the region of New Caledonia and Fiji, characterized by the mixing of relatively low-salinity (34.69‰) surface waters of the South Equatorial Water mass with surface waters of the higher-salinity (36.53‰) West Central South Pacific Water mass during the month (December) closest to our sampling. The break in pon-

tellid distribution found in association with the 34.5‰ isohaline in the present study was also located in this same region (latitude 10° to 20° S, longitude 175° E to 175° W). Rochford's report represents hydrographic conditions during 1955–1956, making comparisons questionable. Nevertheless, it provides a basis for discussing the possible relation between pontellids and surface water movement.

Pontella fera was the only pontellid abundant in waters with salinities below 34.5‰. This water was in the southwestern region of the survey area, adjacent to New Caledonia and the New Hebrides Islands (Fig. 6C). Rochford's description of surface water movement in this region in December indicates that the relatively low-salinity (34.69‰) South Equatorial surface water moves southwest from its region of origin (100% composition), between longitudes 160° E and 180°, latitudes 5° to 10° S, into the higher-salinity (36.53‰) West Central South Pacific surface water in the immediate vicinity of New Caledonia and Fiji. During the months of sampling, January and February, the flow pattern in this region changes substantially from a generally easterly direction from April to December to southerly during the January–March period under the influence of the monsoons, with the equatorial water masses entering the region of New Caledonia from the north and northeast (Wyrtki 1960, p. 30).

This seasonal shifting of the current pattern could explain the low-salinity water in the vicinity of New Caledonia in January and February. Surface waters less saline than 34.69‰, originating from the region of low salinity (Schott 1935, Fig. 27) and high precipitation (Jacobs 1951, Fig. 34) north and west of New Caledonia, could be expected to be transported southward during January and February. The increasing numbers of *P. fera* found with decreasing salinities in this region suggest that waters less saline than 34.5‰ represent the low-salinity South Equatorial surface waters moving into the region from the north and northeast. In contrast, the higher-salinity West Central South Pacific surface waters flow westward from a salinity maximum region (> 35.0‰) into the lower-salinity South Equatorial surface waters, with considerable mixing (50% of each) of these distinct waters occurring in the vicinity of New Caledonia and Fiji during the winter months (Rochford 1959, Pl. 3, 4). The increase of numbers of *Labidocera acutifrons*, *L. detruncata*, and *Pontellopsis villosa* westward, with increasing salinity, suggests that they are closely associated with the West Central South Pacific surface waters.

The five island-associated pontellids occurred within the southern subtropical gyre formed by the South Equatorial Current, west wind drift, and eastern and western boundary currents (Reid 1962). A number of major islands and archipelagos of the Pacific are also located within and adjacent (Malay Archipelago) to this gyral system, including the Marquesas Islands, where Jones (1962) found neritic copepods at distances up to 65 km from land. He ascribed the relatively high offshore plankton volumes to the enriching effect of nutrients carried offshore by currents. The presence of neritic copepods in offshore waters was considered by Jones as supporting evidence of the presence of nutrients of land origin. The occurrence of neritic or littoral copepods in offshore waters could, assuming that Jones is correct, indicate the presence of island-associated water that might be undetected during standard oceanographic observations.

Five species, *Pontella princeps*, *P. securifer*, *P. tenuiremis*, *Pontellopsis regalis*, and *P. armata*, were found distributed over a wide area, in low numbers, and with no apparent relation to either surface salinity or temperature values within the survey region. *Pontellina plumata* was found over a wide area, with greatest numbers located in waters warmer than 26.0C. Three additional species appeared to be affected by temperature change: *Pontella fera*, favoring waters warmer than 28.5C, *Pontellopsis villosa*, favoring waters cooler than that temperature, and *Labidocera detruncata*,

found in decreasing numbers in water cooler than 26.0C.

The differences among the distributions of several pontellid copepods in the central South Pacific show that this group contains a number of species that reflect environmental changes. The specific limiting factor or group of factors has not been determined. However, the close relation to salinity values of *Pontella fera* (low), and of *Labidocera acutifrons, L. detruncata,* and *Pontellopsis villosa* (high) and to island-associated waters of *Pontella denticauda, Pontellopsis macronyx, Labidocera acuta, L. bataviae,* and *L. pavo* attests to the utility of these organisms as biological indicators of low-salinity South Equatorial surface water, high-salinity West Central South Pacific surface water, and island-associated water, respectively.

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Effectiveness of Tilapia as Live Bait for Skipjack Tuna Fishing

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ABSTRACT

In Hawaii, *Tilapia mossambica* is reared as live bait to supplement the chronically short supply of the native bait fish, the nehu (*Stolephorus purpureus*). Effectiveness of tilapia and nehu as bait for skipjack tuna (*Euthynnus pelamis*) was compared in the course of fishing experiments carried out in 1962 in Hawaiian waters. For all sizes of skipjack, slightly more schools responded positively to nehu than to tilapia. Nehu produced higher catch rates (fish caught per minute), and this superiority was more pronounced with large skipjack than with small ones. Since the shortage of bait fish for the Hawaiian skipjack fishery remains critical, further work should be done to develop techniques for using tilapia as bait and to determine whether the availability and hardiness of tilapia can compensate for their inferior effectiveness as bait.

INTRODUCTION

The development of surface tuna fisheries in the central and western tropical Pacific has been held back in part by lack of an adequate supply of live bait. The bait fish problem is critical in the skipjack tuna (*Euthynnus pelamis*) fishery of Hawaii. Suitable habitat for the native bait fish, the nehu (*Stolephorus purpureus*), is limited, availability fluctuates widely, and the species is notorious for poor survival in the bait wells. Hawaiian fishermen spend on the average only 15 days a month in scouting and fishing for skipjack (King and Wilson, 1957). A large part of the remaining time is required for locating and catching bait fish. The economic loss occasioned by the time spent in catching bait fish is aggravated by the sharply seasonal character of the fishery, 77 percent of the annual skipjack landings, on the average, being made in the 5-month period from May through September (Yamashita, 1958). It is evident that a ready, adequate supply of bait during this period would go far toward helping the Hawaiian pole-and-line skipjack fishing fleet to realize its maximum potential production.

Various attempts have been made to alleviate the bait shortage. Brock and Takata (1955)[1] recommended several measures, including mechanical aeration of the bait wells in order to reduce mortality. This recommendation, however, has never been adopted by the fishermen. Other proposed solutions to the bait problem have included the adoption of fishing techniques which do not rely upon live bait and the supplementing of the natural bait supply by introduction of suitable species. Attempts to catch skipjack in commercial quantities using purse seines (Murphy and Niska, 1953) and gill nets (Matsumoto, 1952; Shomura, 1963) have been unsuccessful in Hawaii. Several species have been introduced to Hawaiian waters in the hope that they might prove useful as tuna bait fish. The first such introduction was that of tilapia (*Tilapia mossambica*) (Brock and Takata, 1955). Subsequently, the Marquesan sardine (*Harengula vittata*) was planted in Hawaiian coastal waters (Murphy, 1960) and the threadfin shad (*Dorosoma petenense*) in several streams and reservoirs (Hida and Thompson, 1962). The sardine has not become available in sufficient numbers to be of significance to the skipjack fishery. The threadfin shad has become established, but its effectiveness as skipjack bait has not yet been tested. This species has reproduced successfully in the streams and reservoirs.

The present paper compares the results obtained with nehu and tilapia in experimental

[1] Brock, Vernon E., and Michio Takata. (1955) Contribution to the problems of bait fish capture and mortality together with experiments in the use of tilapia as live bait. Territory of Hawaii, Industrial Research Advisory Council Grant No. 49, Final Report. 39 pp.

pole-and-line fishing that was done incidentally to an experiment in gill-net fishing for skipjack tuna (Shomura, 1963). Since the emphasis was on the gill-net experiments, data on the pole-and-line fishing phase are few, but they are presented here because little information on the performance of tilapia as a bait fish has been published (Brock and Takata, 1955; King and Wilson, 1957).

METHODS AND MATERIALS

From May to August 1962 a number of fishing experiments were carried out aboard the chartered skipjack sampan *Broadbill* in the area of the Hawaiian skipjack fishery. Live nehu were used as chum bait during the first portion of the field work. In July a change was made to tilapia because of the low availability of nehu on the baiting grounds. The tilapia were purchased from a tilapia hatchery set up by the state of Hawaii on a pilot-plant scale to produce bait for the skipjack fishery.

In the field work, detailed records were kept of each bird flock and fish school sighted and the results of fishing, *e.g.*, time of sighting, time chumming was started, species composition of the school, size of fish, amount of fishing effort, and catch. The principal shortcoming of the data is that pole-and-line fishing was not carried to completion on any of the schools, *i.e.*, the maximum possible catch was not realized. In most instances pole-and-line fishing was terminated at the peak of activity in order to set the gill net.

RESULTS

In the Hawaiian skipjack fishery, actively feeding bird flocks are utilized as the principal means of locating fish schools. One of the hypotheses advanced to explain the association is that the sea birds feed on small fish and squid driven to the surface by predatory schooling fishes. A necessary assumption in the present discussion is that in every case where an actively feeding bird flock was approached and bait was chummed there was a skipjack school present, even though fish were not caught or even seen.

The size of bait fish and size-associated differences in their behavior may be critical factors affecting the response of skipjack to them. King and Wilson (1957) observed that tilapia larger than about 75 mm tended to sound when used as chum, while smaller tilapia tended to stay near the surface and swim along with the boat. Tilapia and nehu used in the present study were of generally the same size. The average standard length of tilapia from a sample of 100 fish was 29 mm, while the average size of a similar sample of nehu was 34 mm.

TABLE 1.—*Comparison of effectiveness of nehu and tilapia in inducing skipjack schools to bite*

	Nehu	Tilapia
Total number of schools chummed	74	73
Number of schools abandoned as too small or wrong species	12	21
Number of schools fished without any catch	29	30
Number of schools from which one or more fish were caught	33	22

For convenience in discussion the skipjack schools have been classified as small skipjack (less than 3.6 kg), medium skipjack (4.1 to 6.8 kg), and large skipjack (more than 6.8 kg).

A summary of the schools chummed with nehu and tilapia and the results of fishing is given in Table 1. Fishing efforts were halted after the initial chumming and before any fish were taken from 12 schools chummed with nehu and 21 schools chummed with tilapia, because the fish were judged to be either very small skipjack (less than 1.8 kg) or species other than skipjack, *e.g.*, dolphin (*Coryphaena hippurus*) or yellowfin tuna (*Thunnus albacares*).

Of the schools on which chumming was continued until a definite response or lack of response could be determined, 33 out of 62 (53 percent) of those chummed with nehu yielded catches of one or more skipjack. This minimum criterion of response was met by 22 out of 52 (42 percent) of the schools chummed with tilapia. By way of comparison, Royce and Otsu (1955), studying the results of fishing from a research vessel in Hawaiian waters, reported that 43 percent of the skipjack schools chummed responded to nehu. Yuen (1959), analyzing data from commercial fishing in the same area, found that 48 percent of the schools chummed with nehu yielded catches.

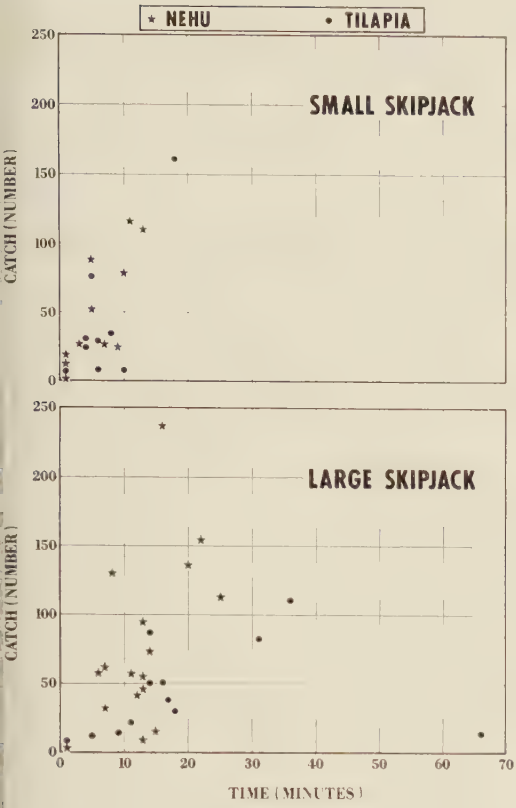

FIGURE 1.—A comparison of catch rates obtained with nehu and tilapia on small and large skipjack.

In some cases it was possible by visual observation to ascertain the approximate size of the skipjack even in the schools from which no fish were captured. Data pertinent to the relation of response to fish size and kind of bait are presented in Tables 2 and 3. Although the sample is small, it appears that there is no direct relationship between size of skipjack and response to either bait.

Figure 1 shows the catch and the duration of fishing for a number of schools of small and large skipjack. For small skipjack, the average catch rate with nehu as the bait fish was 8.4 fish per minute, while with tilapia the catch rate was 6.2 fish per minute. The difference in catch rates was more pronounced with large skipjack. The average catch rate with nehu of 6.1 fish per minute was considerably higher than the 2.9 fish per minute taken with tilapia. The distribution of the catch rates for individual schools (Figure 1) shows that the higher average catch rate for large skipjack was not due to a few exceptionally good catches but to the consistently superior effectiveness of nehu.

TABLE 2.—*Numbers of completely unresponsive schools, by size of component skipjack and kind of bait used*

School composition	Nehu	Tilapia
Small skipjack	3	3
Medium skipjack	2	2
Large skipjack	1	3
Unidentified fish	23	22
Total	29	30

DISCUSSION AND SUMMARY

On the basis of the present data, tilapia does not appear to be as effective a bait fish as nehu for pole-and-line fishing of skipjack. While the ability to produce a catch of at least one fish from a school is nearly the same for the two bait species, the catch rate of large skipjack with nehu was twice that obtained with tilapia. These preliminary results should, however, be viewed with caution. Yuen (1959) examined commercial fishing operations in which nehu was used as the bait fish and found that skipjack response in pole-and-line fishing varied considerably, *e.g.*, the duration of fishing for 86 skipjack schools ranged from 1 to 82 minutes. Moreover, the catch rate (number of skipjack/hook-minute) differed considerably from school to school and with time for the same school.

In this comparison of the two species of bait fish, several conditions unfavorable to tilapia should be taken into account. While the development of nehu as a successful bait fish has been carried out over many years, tilapia is new to Hawaiian fishermen. There has not yet been time enough to determine the best procedures for fishing with tilapia, *e.g.*, size of bait, chumming rate, vessel speed, and type of hook. For example, at present the fishermen use a bright, shiny lure, which is comparable in reflection and color to the

TABLE 3.—*Numbers of responsive schools, by size of component skipjack and kind of bait used*

	Nehu	Tilapia
Small skipjack	14	9
Medium skipjack	2	0
Large skipjack	17	13
Total	33	22

nehu but presents a considerable contrast to the darker tilapia. Conceivably an increase in catch could be attained by employing a dull-colored lure when tilapia is used as the bait fish.

If tilapia is considered as a supplement to nehu rather than a substitute, several advantages become apparent in spite of the difference in effectiveness indicated by this study. Because tilapia is considerably hardier than nehu, it might be used to advantage during periods when skipjack schools are scarce in the usual fishing grounds. At such times, when the boats must range farther and scout longer to find fish, the use of nehu is inefficient, because the high mortality of nehu in the bait wells necessitates replenishing the bait supply after 3 to 5 days of scouting. Tilapia, on the other hand, can be carried in the bait wells with only negligible losses for 2 to 3 weeks or longer. This ability to carry tilapia for long periods would maximize scouting time and thereby increase the probability of locating the skipjack schools.

A second situation where tilapia could serve well as a supplementary bait is during periods of low availability of the nehu, especially when these occur during the skipjack fishing season. When fishermen have to spend 2 to 3 days in locating an adequate supply of bait fish for only 1 day of fishing, they would definitely benefit by using tilapia.

In conclusion, nehu appears to be a more effective bait fish for skipjack tuna than tilapia; however, in view of the shortcomings of nehu, *e.g.*, fluctuating availability and low viability, further studies should be made to develop tilapia up to its maximum efficiency as a supplementary bait fish. There is also a need for a more thorough evaluation of the comparative advantage to the fishermen of spending their working time in fishing skipjack with the readily available and more durable though somewhat less effective tilapia rather than in the more time-consuming and frequent baiting made necessary by the use of nehu.

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20. A New Look at an Old Ocean

The sea has from very early times been a source of fascination and perhaps despair to those interested in puzzling out its mysteries.

Scientific oceanography dates from the work of Maury, *circa* 1835, who published the first charts of winds and currents based on compilations of detailed records. His charts of average conditions formed the philosophical basis for modern oceanographic studies.

The study of marine communities began in about 1835 by Forbes, who established the modern discipline of marine biology by making extensive surveys and analyses of systematically collected specimens. The studies of average oceanic properties and the taxonomy and biogeography of marine communities can hardly be said to be complete. For very large parts of the ocean we know little or nothing of its properties, much less its inhabitants.

But important philosophical changes in our approaches to the oceans are taking place, in that there is a growing recognition of the importance placed by cyclical events which repeatedly occur in physical properties and biological communities. Intuitively, we know these events to depend on the influence of our nearest star, whose life-giving light is converted into biological energy and whose heat is moderated and distributed by the thin film of water which covers such a large part of our planet. In order to relate time sequence changes back to the primary energy sources, our attention is turning from descriptions of properties to a descriptive analysis of changes in individual properties and the effects of a change in one part of the system on other parts of the system.

Such an approach has led us to describe our work in general terms as a study of the animal in its environment, and needing to focus on some of the many animal communities, we have chosen the tunas and their associated companions.

LUCIAN M. SPRAGUE
U. S. Bureau of Commercial Fisheries

1964. /Abstract/ Proceedings of the Hawaiian Academy of Science. 39th Annual Meeting, 1963-1964, p. 25.

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RESEARCH REPORT 63

AN AERATING DEVICE FOR SALT WELL WATER

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Abstract.—Salt well water appeared to be a suitable medium for captive oceanic skipjack tuna except that the available supply was devoid of dissolved oxygen. A model aerating device, whose characteristics could be varied, was used to determine the features of a definitive aerator. The aerator was a tower containing 16 perforated horizontal trays spaced 2 inches apart; the well water was pumped to the uppermost tray, from which it showered successively through those beneath, becoming 95 to 100 percent saturated with oxygen when it reached the bottom. Skipjack were later maintained in this water.

A desire to increase the efficiency of capring oceanic skipjack (*Katsuwonus pelnis*) has led the Bureau of Commercial isheries Biological Laboratory at Honolu into a study of skipjack behavior. n addition to a high-seas investigation, ie study has a shore phase in which skipck are confined in ponds under controlled nditions. Because earlier attempts to tablish skipjack in ponds were unsuccessul (Tester, 1952), a large amount of preminary planning was undertaken in rder to avoid what were regarded as pitlls in the capture, handling, and mainnance of these sensitive fish.

Of utmost importance was the need for n abundant supply of clean, circulating ea water, preferably water of an oceanic ather than a littoral character. The Labratory's dock and pond facilities are loated in Kewalo, a Honolulu district with aree sources of salt water: Kewalo Basin, ie Pacific Ocean, and salt ground water ig. 1). Although Kewalo Basin is imediately adjacent to the Laboratory onds, its water was eliminated from consideration because of a variable contamination from industrial and maritime sources, and also because the small size of its water body might result in a drastic salinity drop during heavy rains. In addition, Kewalo Basin water is rather turbid, a condition deemed unsuitable for ecological and observational reasons. The cost of pumping Pacific Ocean water across 300 to 700 yards of reef and shore seemed prohibitive; also tending to eliminate ocean water were similar, if lesser, problems of contamination and dilution.

FIGURE 1.—Bureau of Commercial Fisheries dock facilities at Kewalo Basin, Honolulu, with the Pacific Ocean in the background.

Editor's note: Later developments of this system are escribed in the paper by Eugene L. Nakamura, which llows this one.

USE AND PROPERTIES OF WELL WATER

Because of the unsuitability of these sources, two salt-water wells were drilled at Kewalo in June 1958. The bores passed through hard-packed coral and sand to depths of 77 and 67.5 feet, of which the upper 42 feet were lined with 3½-inch casing (fig. 2). In November 1958, pumps

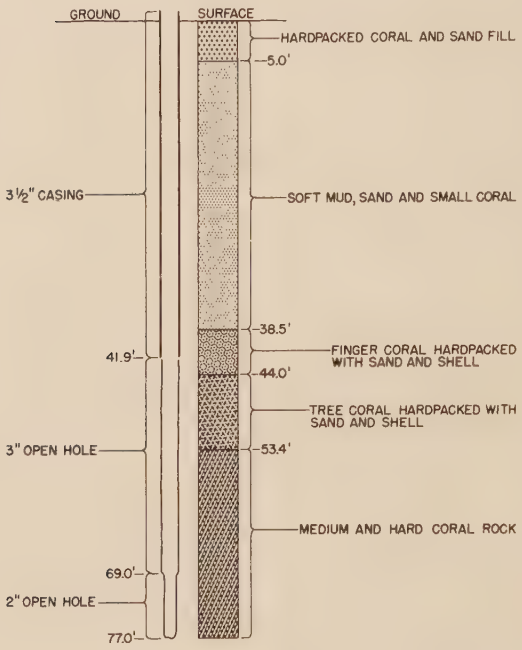


FIGURE 2.—Diagram of Kewalo well and surrounding stratigraphy.

were fitted to both wells, and studies were begun on the fitness of the water for maintaining various fish. Heavy pumping caused the shallower bore to become impacted with sand, but the 77-foot well has been in nearly continuous operation since that time. About 35 million gallons had been pumped in 20 months at rates varying from 30 to 45 gallons per minute. At these rates the drawdown of shaft water level was only 0.4 feet. Some properties of this water are listed in table 1, along with similar data for the Honolulu Aquarium well (3 miles from Kewalo) and oceanic water. The Kewalo and Aquarium samples were drawn on December 10, 1958, while the ocean water values were compiled from various sources, including the Honolulu Board of Water Supply. The analyses were performed by Y. F. Lee of the Honolulu Board of Water Supply, to whom I am indeed grateful.

The Kewalo and Aquarium samples differed from ocean water in chlorinity and pH, both items of concern to aquarists. The pH deficiency was easily remedied by heavy aeration of the incoming water, the pH value rising to 8.1 in about 40 minutes. The effects of brackish water on skipjack were unknown, but the slightly low salinity of the Kewalo water did not seem likely to be a serious problem. There remained to be determined, however, the salinity range to be expected following heavy rains and extensive percolation of pluvial water. Salinity and rainfall data are presented in figure 3, from which it is evident that rain had little diluting effect on the water supply.

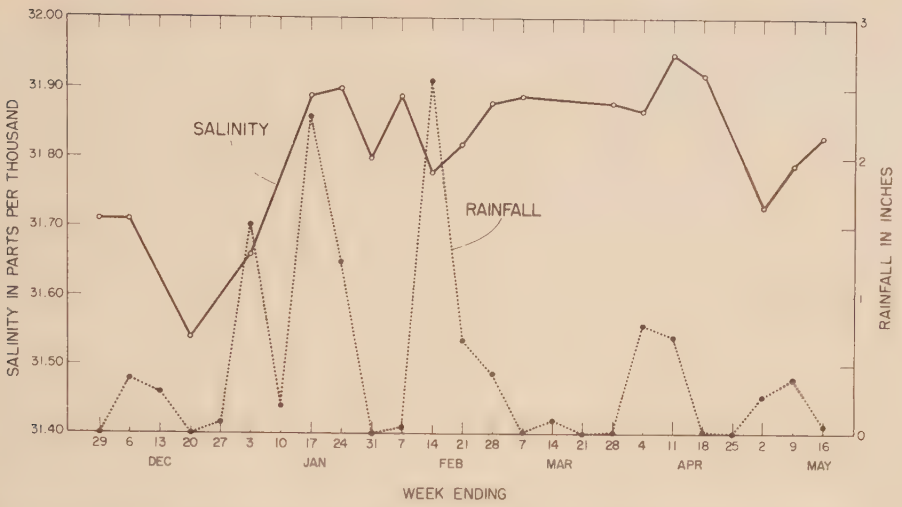
Table 1.—*Some properties of Kewalo and Honolulu Aquarium well water and the nearby ocean*

[All values as mg./L. except pH]

	Kewalo	Aquarium	Ocean
pH	7.50	7.55	8.25
Silica	22	17	3
Calcium	400	438	405
Magnesium	1,211	1,251	1,315
Sodium	10,400	10,000	10,540
Potassium	365	375	400
Bicarbonate	144	137	----------
Sulfate	2,440	2,530	2,610
Chloride	17,800	18,400	19,150
Phosphate	0.10	0.10	0.20
Alkalinity [1]	118	112	115
Hardness [1]	5,965	6,225	6,400

[1] As $CaCO_3$ equivalent.

Conspicuously absent from table 1 are data on the dissolved oxygen in the well water. Winkler analyses of water direct from the pump gave oxygen values of 0.15 to 0.69 ml./L, the mean of 14 samples being 0.30 ml./L. This inadequacy was at first remedied by pumping the water over a perforated tray, from which it showered into a large tank containing reef fish. Al-



GURE 3.—Salinity of Kewalo well water and amount of rainfall at Federal Building, Honolulu, November 1958–May 1959. Rainfall data compiled by U.S. Weather Bureau.

lough the oxygen content of this aer-ed water was as high as 2.34 ml./L, the shes tested (*Abudefduf*, *Acanthurus*, *rothron*, *Chaetodon*, *Parupeneus*, *Perva-or*, and *Zanclus*) did not thrive; in fact, any died within one or two days. In closed-circuit control tank the oxygen vel was maintained at 4.90 ml./L by con-nuous aeration with breaker stones, and ere similar test fish did very well. It emed obvious that an efficient aerating evice must be an integral part of the umping setup if circulating well water as to be employed.

AERATING DEVICES

A cursory survey of the literature plus orrespondence with several aquarists re-ealed that little was known, or published, bout the problem at hand. Specifically, device was needed for bringing oxygen-oor water to the saturated state under igh-flow conditions, and so constructed hat oxygenation and circulation were con-omitant features, eliminating any possi-ility of fish mortality from exposure to eoxygenated ground water. This require-ent eliminated from consideration cer-ain apparatus (Venturi systems, com-ressed gas liberators, and agitators) of great utility elsewhere (Norris et al., 1960). The field of choice was narrowed to sprays, cascades, and the like, where the influx of water per se results in aeration.

Plans for the aeration apparatus began to emerge when the physical conditions at Kewalo were considered. Beds of spraying fountains or shallow, baffled spillways were precluded by limited ground space, and the height of a tower from which water could fall was limited by the pumping pressure. Of various devices mentioned in the literature (Shaw, 1936; Betz Laboratories, 1957; McKelvey and Brooke, 1959), a compact block of stacked perforated trays seemed to be the most promising. Oxygen-free ground water would be pumped to the uppermost tray, from which it would shower successively through several lower trays, becoming saturated with oxygen just as it reached an aquarium below. The optima for tray spacing, number and size of tray perforations, rate of water flow, and tray number had yet to be determined.

EXPERIMENTAL AERATOR

To discover the interaction of these variables a model aeration device was con-

structed and a number of experiments were performed. Attention was focused on variations in dissolved oxygen resulting from different numbers and spacings of trays, while perforation size and number were held constant. Flow rate was necessarily low because of the miniature size of the equipment, but it was essentially constant at 182 to 193 milliliters per second (3 gallons per minute). Water temperature was also approximately constant, the range being 74.2° to 77.8° F. over the test period but with a fluctuation of less than 1 degree on any one day.

The apparatus assembled for a test is shown in figure 4; it consisted of the following parts: an open-faced wooden cabinet with a bottom drain and valve; an 11½-inch square wood and plastic inlet tray (actually an "under-gravel" filter) having 289 perforations and a brass nipple for attaching a hose; a number of 11½-inch square wooden trays having 144 perforations and no nipple; an ordinary ¾-inch plastic garden hose; a supply of metal C-clamps for positioning the trays in the cabinet; several sheets of thin vinyl plastic which were stretched across the face of the cabinet to prevent splashing; a short length of siphon tubing (not shown); and chemical equipment for determining dissolved oxygen by the Winkler method. In practice the flow rate, temperature, and amount of oxygen in the unaerated water were first measured, followed by the collection of samples from beneath varying numbers of equally spaced trays. The water samples were drawn from the bottom valve or by siphon; the drain was stoppered until 1 inch of water had accumulated in the cabinet's base, at which time a sample was taken.

Figure 5 shows the relations between tray spacing, tray number, and dissolved oxygen obtained from experiments with the model aerator. All oxygen values are shown in terms of percentage saturation

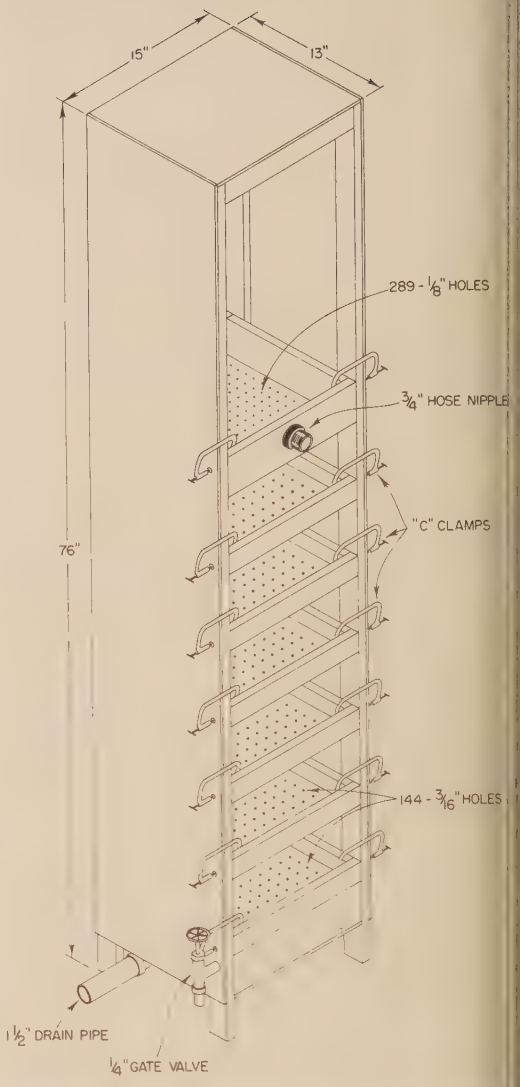
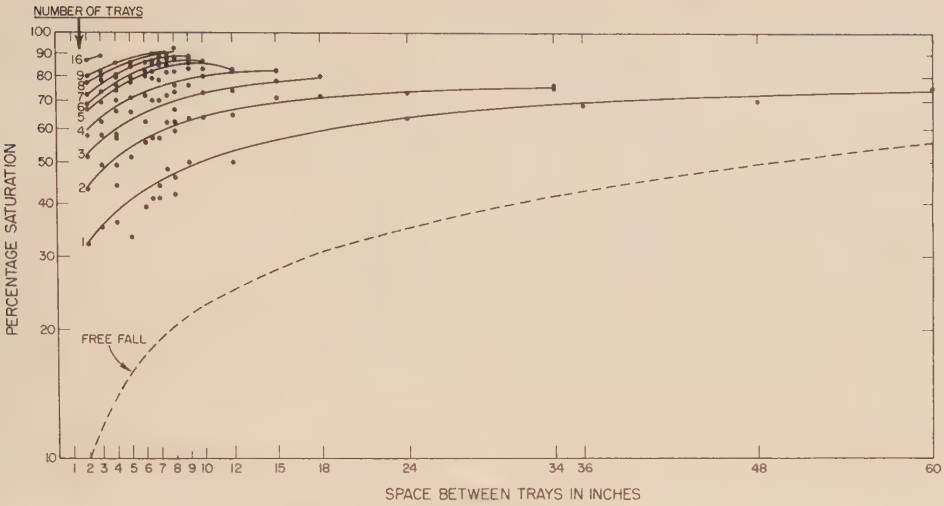


FIGURE 4.—Model aeration device used to determine effects of tray spacing and number on amount of dissolved oxygen in water. Water was supplied to the topmost tray by a hose attached to the nipple.

for the particular salinity and temperature prevailing at the time of the test (the percentage saturation was obtained from data presented by Sverdrup et al., 1942, p. 188). The curves were fitted by eye to coincide with the maximum number of points. Not shown in the crowded upper left portion of the figure are data from tests using 10 to 15 trays; the curves from these tests lay between those for 9 and 1



GURE 5.—Relation between percentage oxygen saturation, tray number, and tray spacing. Broken line represents time/distance relation for a body in free fall.

ays. Also not evident is the oxygen con-nt of the incoming water; this ranged om 0.15 to 0.69 ml./L, but was most ten 0.17 to 0.20 ml./L. The highest turation achieved with the model aerator as 93 percent; the highest obtained by olonged bubbling of air through the ater was 96 percent.

Two aspects of figure 5 merit brief scussion. The first is the shape of the turation curves: as is apparent, these ave the general conformation of the curve describing the distance traveled by a freely falling body. Saturation is a function of the amount of exposure to air, and this varies with drop size, velocity, and height of fall. The left portion of each saturation curve is flatter than the corresponding part of the free-fall curve, undoubtedly representing additional exposure to air because of splashing, flow over the tray surfaces, or a velocity decrease caused by air resistance. Also contributing to the shape of the curves are such factors as water

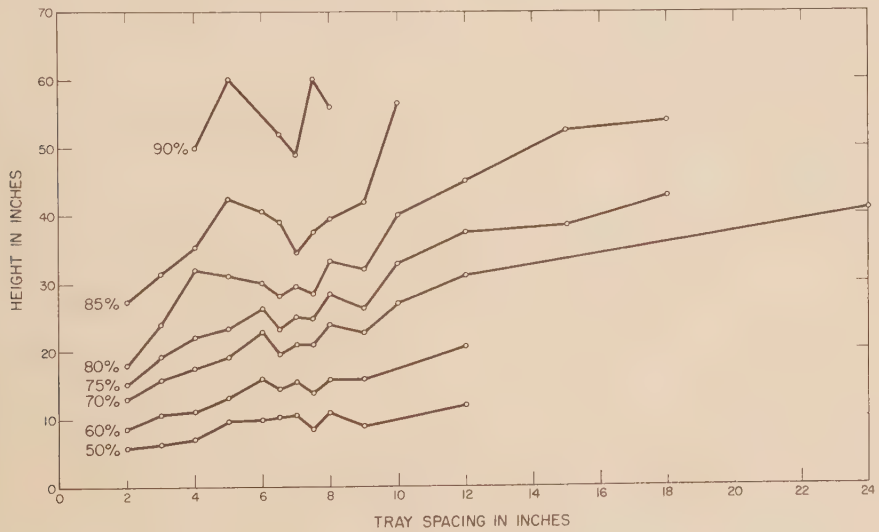


FIGURE 6.—Height of aerator needed to produce a given percentage of oxygen saturation.

films flowing down the cabinet walls, water drops falling cleanly through perforations aligned by chance, occasional stream-flow through a perforation, and the difficulty in adding oxygen to water as the saturation point is approached.

The second interesting feature of figure 5 is the relative importance of tray spacing versus number of trays. Although the same degree of saturation can be attained with either a few widely spaced trays or several closely spaced ones, there are practical considerations to be borne in mind when planning a definitive aerator. Wide tray spacing results in a tall aerator, requiring considerable pressure for pumping water to the top. Narrow tray spacing means a short device with numerous trays, the latter sometimes being expensive to construct and usually difficult to clean. Figure 6 shows the relative unimportance of tray spacing, for a con-

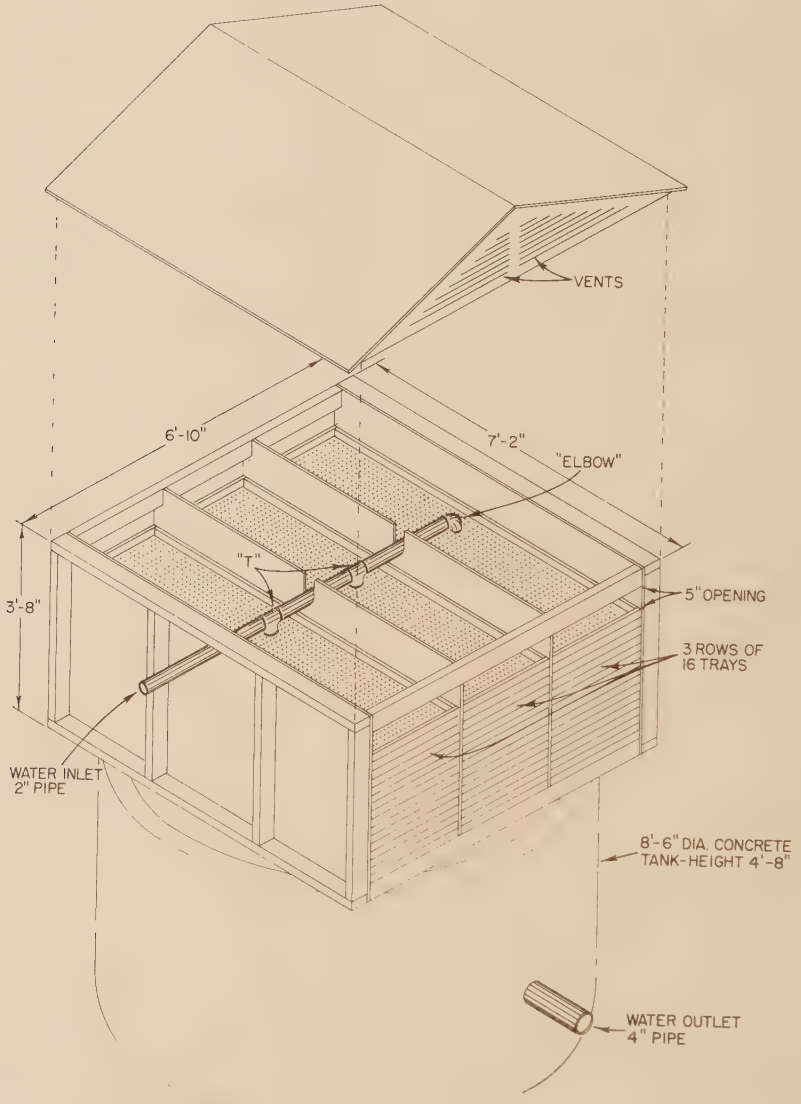


FIGURE 7.—Aerator developed for use with salt well water.

ant tower height, when only a low or oderate degree of saturation is desired. s higher degrees of saturation are at- ined, then the aerator becomes increas- gly tall and spacing increasingly nportant.

DEFINITIVE AERATOR

Since it was desired to use highly turated water as a medium for skipjack, me extrapolation was done from the pper curves of figures 5 and 6 in planning ie definitive aerator. It was decided that 3 trays spaced at 2-inch intervals would rovide near saturation with a moderate ressure requirement, and if these trays ere perforated with ⅛-inch holes at ½- ch intervals there would be sufficient apacity to carry water at flow rates up to bout 100 gallons per minute (and per- aps more). A diagram of the aerator ltimately built from these plans is shown figure 7, from which the following eatures will be noted. The aerator is ssentially a wooden box surmounting a oncrete tank which receives the aerated ater. The ends of the aerator are slotted or ingress of air, but light is excluded s much as possible to inhibit the growth f algae. Within the box are three rows f 16 long, narrow trays, which can be ulled out like drawers for cleaning or nspection. All construction is of wood except for the perforated tray bottoms, which are of pressed fibreboard doubly coated with an epoxy resin. The aerator has been in nearly continuous use for 18 months with only slight attention being required. Tray cleaning has not been necessary. Water passed through it ranged from 95 to 100 percent saturated with oxygen, and was successfully used for the maintenance of skipjack (see Nakamura, this collection).

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Further Notes on the Identification and Biology of Echeneid Fishes

DONALD W. STRASBURG[1]

ATTEMPTS TO IDENTIFY several small echeneid fishes revealed that some of the more useful adult characters are not present in the young. Specifically, disk length, pectoral fin rigidity, body and fin morphology, and scale size and number are features which change with growth. Certain meristic characters were found to be constant over the 14 to 640-mm length range considered, and were usable in identifying small specimens. This paper presents a key to the Echeneidae with further observations on their biology.

The methods employed require only brief description. The leathery membranes were removed from the fins of all but the smallest individuals in order for the rays to be counted. This was particularly necessary for the dorsal fin, the anterior rays of which are recumbent and would otherwise escape detection. The uppermost pectoral ray, a short bony splint, was counted as a ray. Scale examination involved removing a small square of skin from the side below the rear edge of the disk, staining this square with alizarin, and removing the rubbery epidermis. Both lateral line and ordinary scales were then visible in this piece of tissue. No type material was examined, nor was it possible to see specimens of all species. The names used are in accordance with Maul (1956).

Table 1 presents the meristic data obtained from specimens in the collection of the Bureau of Commercial Fisheries Biological Laboratory in Honolulu. These data are the main basis for the following key, although supplementary information was used for the species not seen and to broaden the range of some characters. This information was obtained from the following reports: Bigelow and Schroeder (1953:485–487), Breder (1936:43), Cadenat (1950:265; 1953:674–680), Clemens and Wilby (1949: 329), Clothier (1950:51), Follett and Dempster (1960:172–176), Fowler (1941:269–275), Hildebrand (1946:479), Jordan and Evermann (1898:2268–2273), Krefft (1953:278), Maul (1956), Meek and Hildebrand (1928:896–899), Munro (1955:268), Schultz (1943:258–260), Smith (1950:341–342; 1958:319), and Szidat and Nani (1951:399–407).

The two species of *Remoropsis* recognized by Maul (1956) do not differ meristically, nor are they clearly distinguishable by other means. In general, the body scales of *brachypterus* are large, closely spaced, and superficial, while those of *pallidus* are small, scattered, and embedded. In large *brachypterus,* however, the scales are partially embedded, and, in addition, some *pallidus* have large scales. The shape and spacing of the lateral line scales varies from point to point along the lateral line, and Strasburg (1959: 244) found specimens with the coloration of *pallidus* but the lateral line of *brachypterus.* These facts suggest that *pallidus* and *brachypterus* are very closely related, if not synonymous. In the absence of a definitive monograph, they are retained as distinct species characterized solely by color pattern.

The length of the sucking disk has sometimes been used as a taxonomic character in the Echeneidae (cf Maul, 1956:18). *Rhombochirus* has been distinguished from the other genera, exclusive of *Remilegia,* by the fact that its disk reaches to or past the pectoral tips. The posterior extent of the disk and pectoral fins of echeneids of various lengths is shown in Figure 1. Below 65 mm standard length the pectorals of *Rhombochirus* extend farther posteriorly than the disk, as is always the case with *Remora, Remoropsis,* and *Phtheirichthys.* While this character may be used for large individuals, it

[1] U. S. Bureau of Commercial Fisheries Biological Laboratory, Honolulu, Hawaii. Manuscript received September 26, 1962.

TABLE 1

FREQUENCY DISTRIBUTION OF MERISTIC CHARACTERS IN CENTRAL PACIFIC ECHENEIDAE

CHARACTERS		NO. OF LAMINAE OR FIN RAYS																														
		9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
disk laminae,	*P. lineatus*	1	7	3																													
	R. osteochir									8	36	9	1																				
	R. remora									13	15	1																					
	R. pallidus							4	7	7	1																						
	R. brachypterus								3	3																							
dorsal rays,	*P. lineatus*																						1		1	1	2		3	1	1		1
	R. osteochir													2	5	13	17	10	6	1													
	R. remora														2	4	12	8	3														
	R. pallidus																				2	3	4	7		3							
	R. brachypterus																				1			4	1								
anal rays,	*P. lineatus*																						1			1	2	1	4	2			
	R. osteochir													1	13	18	15	5	2														
	R. remora														3	19	7																
	R. pallidus																	4	7	7	1												
	R. brachypterus																	2	2	2													
pectoral rays,	*P. lineatus*									1		6	2	1																			
	R. osteochir												1	19	27	7																	
	R. remora																		8	16	4	1											
	R. pallidus																	3	15	1													
	R. brachypterus																	2	2	2													

KEY TO THE ECHENEIDAE

a. Disk laminae 13 or fewer
  2a. Laminae 9–11, dorsal 30–40, anal 29–38.....*Phtheirichthys lineatus* (Menzies)
  2b. Laminae 12–13, dorsal 16–22, anal 20–26.....*Remorina albescens* (Schlegel)

b. Disk laminae 14 or more
  3a. Laminae 20–28, usually 21–27
    4a. Dorsal 31–42, anal 30–38.....*Echeneis naucrates* Linnaeus
    4b. Dorsal 20–26, anal 20–26.....*Remilegia australis* (Bennett)
  3b. Laminae 14–20, usually 15–19
    5a. Dorsal 21–27 (usually 22–26), laminae 17–20
      6a. Pectoral 20–23.....*Rhombochirus osteochir* (Cuvier)
      6b. Pectoral 26–29.....*Remora remora* (Linnaeus)
    5b. Dorsal 28–33, laminae 14–18 (usually 15–17)
      7a. Caudal black with white corners in specimens 27–164 mm standard length; dorsal and anal black with white edges, white becoming obsolescent with growth.....*Remoropsis brachypterus* (Lowe)
      7b. All fins uniformly pale colored.....*Remoropsis pallidus* (Schlegel)

TABLE 2

HOSTS OR HABITS OF ECHENEID FISHES

ECHENEID	NO. EXAMINED	STANDARD LENGTH (mm)	HOST OR HABIT
htheirichthys lineatus	3	32.8–300	free-living
	5	44.0–55.8	long-line buoy or bait
hombochirus osteochir	4	14.3–45.7	free-living
	1	51.2	long-line buoy
	1	48.4	*Acanthocybium solandri*
	4	66.7–85.0	*Tetrapturus angustirostris*
	11	49.8–230	*Makaira audax*
	27	38.5–313	*Makaira ampla*
emora remora	7	31.3–77.4	free-living
	2	49.3–87.6	*Carcharhinus melanopterus*
	12	50.9–154	*Pterolamiops longimanus*
	1	222	*Prionace glauca*
	1	640	*Rhincodon typus*
emoropsis brachypterus	1	27.1	free-living
	1	80.0	*Makaira audax*
	2	83.7–112	*Makaira ampla*
emoropsis pallidus	1	118	free-living
	2	79–83	*Istiophorus orientalis*
	4	116–184	*Makaira audax*
	2	128–152	*Makaira ampla*
	5	128–194	*Istiompax marlina*
cheneis naucrates	2	50–57 (est.)	*Ostracion lentiginosus* and the author

is clear that *Rhombochirus* shorter than about 65 mm cannot be distinguished from the other genera by the disk length/pectoral length relationship.

Table 2 summarizes the length and host data for the specimens listed in Table 1. Where the host was identified only as "marlin" or "shark" no listing was made in Table 2. Also excluded are three echeneids removed from fish stomachs: a 46-mm *P. lineatus* and a 118-mm *R. pallidus* from *Neothunnus macropterus,* and a 56-mm *R. osteochir* from a "swordfish." The term "free-living" denotes echeneids captured by plankton net, midwater trawl, or dipnet beneath a light.

An aspect of echeneid biology which merits some discussion is the change in habit or host with growth. As shown by Strasburg (1959), attachment tends to be specific with respect to host and attachment site. For example, *Phtheirichthys* is either free-swimming or attached

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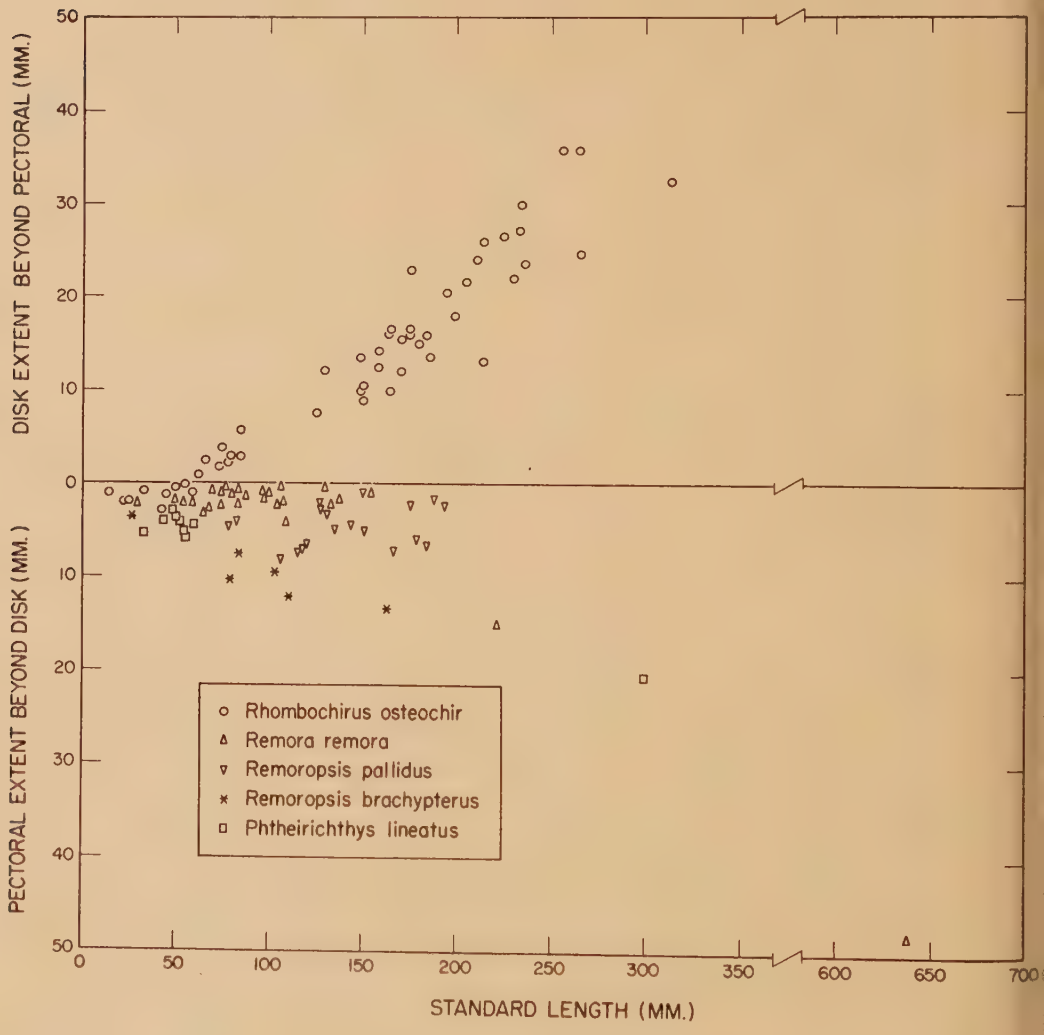

FIG. 1. Relative posterior extent of sucking disk and depressed pectoral fin for various echeneids.

FIG. 2. *Echeneis naucrates* attached to *Ostracion lentiginosus*. Standard lengths estimated to be 57 and 49 mm respectively. (Photograph by Charles E. Cutress, U. S. National Museum.)

to immotile objects, *Remora* is found externally on sharks, and *Remoropsis pallidus* takes refuge beneath the opercula of marlins. Although it is known that the early stages are planktonic, there has hitherto been no information on the size at which attachment first occurs, or whether there are trial hosts.

The material at hand indicates that the transition from the free-swimming to the attached state occurs at about 40–80 mm standard length. *Phtheirichthys* then attaches to immotile objects, as occasionally do some of the others. *Rhombochirus* selects a variety of marlin-like fishes for its attachment, while *Remora* attaches to sharks. One of the *Echeneis* studied was attached to a 49-mm trunkfish, *Ostracion lentiginosus* (Fig. 2), collected on the reef at Waikiki, Oahu, Hawaii. Except for a few brief excursions to the host's belly, it remained inverted as shown. Unfortunately, neither the echeneid nor the trunkfish was preserved, and their lengths are only estimates derived from the relative proportions shown in the photograph. The second *Echeneis* could not be captured but was also about 50 mm in length. It joined me while swimming in 10-ft deep water at Beaufort, North Carolina. Its black and white pattern made it conspicuous, and it was sighted at a distance of 15 ft, swimming directly toward me. The fish made numerous attempts to attach to my black swim fins, touching them but not actually attaching because of my continuous movements. It eluded all attempts to capture it.

It would seem that attachment becomes obligatory somewhere in the 40 to 80-mm length range. Alternate hosts, such as *Acanthocybium, Tetrapturus,* and *Carcharhinus melanopterus,* may then be selected in the absence of the definitive host species. These small hosts may be regarded as trial vehicles because they bear only small echeneids. The size of the echeneids carried by them would be restricted by the relatively fewer ectoparasites available as food or, as in the case of the *Ostracion–Echeneis* association, by problems of list and drag resulting from a bulky adherent.

As a corollary, one would expect large echeneids to select large hosts or, in their absence, to revert to free swimming. The latter appears to be the case with *Echeneis naucrates,* 39-inch individuals of which are free-living around piers at Eniwetok, Marshall Islands (Strasburg, 1957: 60). The 640-mm *R. remora* listed in Table 2 confirms the first part of the hypothesis, for it was one of about three dozen individuals of similar size accompanying a 50 to 60-ft whale shark, *Rhincodon typus,* at Maro Reef (northwest of the main Hawaiian Islands). Attempts to lure this shark to the fishing vessel were unsuccessful because the chopped fish bait was intercepted by the darting remoras. Twelve remoras were caught by pole and line using tuna flesh as bait, but only a single specimen was preserved. Its stomach was empty, unfortunately, so that no light can be shed on its diet. It is doubtful that such a large fish could subsist mainly on its host's ectoparasites (cf Strasburg, 1959:246).

Some of the smaller specimens listed in Table 2 are the smallest reported representatives of their species. The 27.1-mm *brachypterus* is considerably shorter than Gudger's (1928) 77-mm fish, and my 14.3-mm *osteochir* is smaller than his 36-mm specimen. Gudger presents few descriptive data, however, and his specimens seem to differ from what are here called *brachypterus* and *osteochir.* On the basis of pectoral counts, Beebe's (1932) 15-mm *"Remora remora"* is *Rhombochirus osteochir,* while his 88-mm specimen is correctly identified as *R. remora.*

Beebe (ibid.) also misinterpreted certain morphological peculiarities of the lips and jaws of his small *osteochir.* These were stalked cup-like structures which he termed "suckers," and which he postulated were used for host attachment prior to the development of the cephalic disk. Actually the "suckers" on the mandible are the enlarged fleshy sockets which normally bear the fangs, while those on the upper lip are merely large pores. The fangs are easily extracted with forceps, imparting a sucker-like appearance to the supporting tissues. My 14.3-mm *osteochir* has seven outer and two inner fangs on each side of the mandible, making a total of 18 sockets. This is a reasonable approximation of the 20 "suckers" and four fangs which Beebe found in his 15-mm fish.

The young echeneid's need for its relatively enormous fangs is presently inexplicable. These teeth are not deciduous but instead become inconspicuous through overgrowth of the gums and the appearance of other teeth between them.

Its intimate association with another species could impose serious reproductive restrictions on an echeneid. Unless both sexes attached to the same host individual, spawning would be limited to times when the host species aggregated. Echeneids attached to hosts which schooled or congregated to feed would have many opportunities for mating, but those accompanying solitary hosts would have to spawn simultaneously with them.

The material at hand was examined for gonad maturity and the presence of both sexes on the same host individual. Unfortunately, the specimens were not always so segregated that the latter could be determined. Thus, although mature *Remora remora* and *Remoropsis pallidus* were found, it was not certain whether both sexes had been attached to the same shark or marlin. The available *Remoropsis brachypterus* and *Phtheirichthys lineatus* were few and sexually immature.

In contrast to the above, the *Rhombochirus osteochir* data present a relatively clear picture of the physical distribution of the sexes. Thirteen marlin and spearfish bore 2 *Rhombochirus* apiece. In 10 cases the 2 were a male and female of the same size and degree of maturity (7 pairs were judged to be ripe, based on abdominal distension of the female). The 11th pair was a small female and a fish half her size whose sex could not be determined. The remaining 2 couples consisted of young fish of undetermined sex. A 14th host was accompanied by 3 *Rhombochirus,* a ripe male and female and a small individual, one-fourth the length of the others, whose sex could not be ascertained.

With 11 out of 14 pairs bisexual and in the same maturity stage, it would seem that *Rhombochirus* can reproduce quite independently of its host's aggregating habits. This does not mean that it always does so, for mature single *Rhombochirus* were also collected. In such cases, however, there is a possibility that these fish were remnants of pairs the other members of which had detached during the capture of the host.

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A POSSIBLE BREAKDOWN IN SYMBIOSIS BETWEEN FISHES.—Occasionally, a report on the Echeneidae will record specimens from the digestive tracts of large fishes such as sharks, marlins, and tunas. Such occurrences have received little comment because they are infrequent and the suckerfish are of negligible bulk in the predator's diet. Their importance only becomes apparent when the situation is examined from an ecological point of view. Such occurrences then indicate a possible breakdown in the symbiotic relationship in which many echeneids have been found to pick parasites from their hosts (Szidat and Nani 1951, *Rev. Inst. Invest. Mus. argent. Cienc. nat.* 2(6):413; Maul 1956, *Bol. Mus. Funchal* 9: 14; Strasburg 1959, *Copeia* 3:247). This paper documents six additional instances of echeneids having been eaten by large fish, and also gives an estimate of the frequency of such a phenomenon.

The echeneids *Remoropsis brachypterus*, *Rhombochirus osteochir*, and *Phtheirichthys lineatus* were found in the stomachs of yellowfin tuna, striped marlin, and possibly also blue marlin, although this identification is not certain and the fish may have been a striped marlin (Table 1). Identification of these partially digested suckerfish was in accordance with Maul (*op. cit.*:18–19) where possible, although *Remoropsis pallidus* was regarded as a synonym of *R. brachypterus*. In three instances, the consumer was also the host species (*T. audax* and *M. nigricans* commonly bear *R. brachypterus* and *R. osteochir*) so that the suckerfish prey could have been the hosts' cleaners. In three other instances, the consumer was not the host species (neither *R. brachypterus* nor *P. lineatus* occurs on *T. albacares*, cf. Strasburg, *op. cit.* and *Pacific Sci.*, in press), and the fact that it ate suckerfish has litle ecological significance.

There are several possible ways by which these suckerfish could have been eaten. All of their consumers were captured by longline which had fished for several hours prior to being retrieved. During this time it would be possible for many echeneid-bearing hosts to be hooked, to die, and as often happens, to lose their suckerfish. Such detached echeneids could be easily picked off by a fast, hungry predator, and they might actually cause their own destruction by attempting to attach to passing foraging species. In my experience, yellowfin tuna do not normally bear suckerfish, and would probably regard any free-swimming individuals merely as food. On the other hand, one would expect the various marlins to exercise some restraint in eating a species with which they have a symbiotic relationship. If the cleaning relation between marlins and echeneids is historically in its early stages, it is possible that a hungry marlin might not always distinguish between its cleaner and its food. Other imperfect relationships, in which the cleaner is sometimes eaten, have been found among shrimp and moray eels (Limbaugh, Pederson, and Chase 1961, *Bull. Mar. Sci. Gulf Carib.* 11(2):250) and the kelp perch and other fishes (Limbaugh 1961, *Sci. Amer.* 205(2):45). Such relationships are intermediate between commensalism and true symbiosis. In the case of the shrimp, *Remoropsis*, and *Rhombochirus*, at least, the cleaner's lack of conspicuous coloration may lead to its occasional downfall.

Possibly the *R. brachypterus* eaten by *T. audax* had inhabited its host's buccopharyngeal region, but had become dislodged and

Table 1. Echeneids Eaten by Large Fish

Echeneid		Predator			
Species	Standard Length (mm)	Species	Weight (lb)	Region	Date
R. brachypterus	91	*Thunnus albacares*	110	02° S, 153° W	15 June 1962
" "	123	" "	141	Off Hawaii	21 July 1960
" "	170	*Tetrapturus audax*	81	Off Oahu	December 1962
R. osteochir	56	" " or *Makaira nigricans*	–	Off Kauai	15 June 1949
" "	280	*Tetrapturus audax*	112	Off Oahu	September 1962
P. lineatus	46	*Thunnus albacares*	118	11° S, 135° W	28 August 1956

swallowed. Also, the various suckerfish listed above may have been dead prior to being eaten.

Two of the suckerfish listed in Table 1 were obtained from *T. audax* landed at the Honolulu Market. Messrs. Howard Yoshida and Frank Moriguchi, of the Bureau of Commercial Fisheries Biological Laboratory, Honolulu, have undertaken a routine stomach sampling of the large market fish. They report that these two suckerfish were the only ones found in 749 stomachs having the following species distribution: *Makaira nigricans*, 96; *M. indica*, 5; *Tetrapturus audax*, 447; *T. angustirostris*, 16; *Istiophorus orientalis*, 21; *Thunnus albacares*, 97; *T. alalunga*, 24; *T. obesus*, 10; *Euthynnus pelamis*, 5; *Acanthocybium solandri*, 5; *Coryphaena hippurus*, 5; *Alepisaurus* sp., 15; and *Sphyraena* sp., 3. Considering only the 585 spearfishes and sailfish, which normally each bear at least two echeneids (Strasburg, *Pacific Sci.*, in press), the ratio of two suckerfish eaten out of more than 1,170 "available" is very low. Therefore, consumption of echeneids by these fish must be a rare event, probably fortuitous, and perhaps related to the fishing method used to capture the hosts.—Donald W. Strasburg, *U. S. Bureau of Commercial Fisheries, Biological Laboratory, Honolulu, Hawaii.*

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ostlarval Scombroid Fishes of the Genera *Acanthocybium, Nealotus,* and *Diplospinus* from the Central Pacific Ocean

DONALD W. STRASBURG[1]

XCLUSIVE of the mackerels and tunas, whose ɔmmercial importance has caused them to be udied extensively, the early life history of ombroid fishes is poorly known. This is parcularly true of the families Gempylidae and richiuridae, even though they are the bases for sheries in Australia, South Africa, Madeira, and arts of Asia. There is also a paucity of life-istory information about the non-schooling combridae. This paper describes young stages of ıe scombroid *Acanthocybium solandri* (Cuvier ıd Valenciennes), the gempylid *Nealotus tripes* ɔhnson, and the trichiurid *Diplospinus multstriatus* Maul, all three belonging to monotypic enera. The first has a slight commercial imortance (Iversen and Yoshida, 1957:370), the thers may be considered rare species of no ɔmmercial value.

The three families are taxonomically well nown, the Scombridae having been reviewed y Fraser-Brunner (1950), the Gempylidae by Iatsubara and Iwai (1952) and Grey (1953), nd the Trichiuridae by Tucker (1956). All of ıese authors dealt essentially with adult fish. ostlarval *Acanthocybium* are hitherto unreɔrded, the smallest specimen mentioned in the terature measuring 27 cm (Kishinouye, 1923: 87). Similarly, the smallest *Diplospinus* is 125 ım (Maul, 1948:45), although there is a posibility that a 69 mm *Lepidopus* may in reality e a *Diplospinus* (Tucker, 1956:81). Small *Neaɔtus* have been recorded by Lütken (1880:458), Günther (1887:35), Norman (1930:351), and Voss (1957:304). Lütken figured his specimens ut regarded their identity as dubious. His larger pecimen (about 13 mm standard length) has 0 spines in the first dorsal and is probably *Nealotus*. His smaller fish measures only about 8 mm in standard length and cannot be identified with certainty.

All material reported upon here was collected by "British Columbia" trawl during cruise 47 of the Bureau of Commercial Fisheries research vessel *"Hugh M. Smith."* This cruise took place in October–November 1958, in the central Pacific southeast of Hawaii. A description of the collection method is included in Matsumoto's report (in press) on the young tunas taken on this cruise. Figure 1 locates the trawling stations and capture sites of the species under consideration. Additional data may be found in Table 1 and in the species diagnoses.

Following capture, the fish were preserved in formalin and subsequently transferred to 65% ethyl alcohol. This particular concentration produced less wrinkling, hardening, and distortion than the customarily used 70% solution. Most specimens were stained with alizarin, but clearing the tissues, as with glycerin, was not done.

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Acanthocybium solandri (Cuvier and Valenciennes)

Station 60 1 specimen: 23.7 mm

The single *Acanthocybium* captured is rather easily recognizable in spite of the fact that its

[1] Bureau of Commercial Fisheries Biological Laboratory, Honolulu, Hawaii. Manuscript received November 13, 1962.

TABLE 1

STATION DATA, "HUGH M. SMITH" CRUISE 47

STATION NO.	DATE (1958)	ZONE TIME	LATITUDE	LONGITUDE	MAXIMUM HAUL DEPTH (in m)
2	Oct. 9	2005–2300	21° 24′ N	158° 23′ W	139
32	Oct. 27	1315–1523	00° 02′ S	149° 32′ W	85
49	Nov. 2	0843–1027	02° 09′ S	149° 47′ W	99
51	Nov. 2	2013–2158	00° 44′ S	149° 46′ W	85
53	Nov. 3	0838–1018	00° 37′ N	149° 58′ W	86
56	Nov. 4	1030–1210	01° 56′ N	150° 09′ W	98
58	Nov. 4	2013–2153	02° 56′ N	150° 03′ W	93
60	Nov. 5	0820–1002	04° 28′ N	150° 29′ W	96
66	Nov. 6	2005–2152	09° 08′ N	150° 03′ W	96
68	Nov. 7	0820–1007	10° 40′ N	149° 52′ W	93
70	Nov. 7	2015–2148	12° 13′ N	149° 56′ W	96

finlets have not yet differentiated. The fin formulae are D XXVII, 24 and A 22 as a consequence of persistent membranes between the fins and presumptive finlets. The anal formula is additionally misleading in that spines and rays cannot be distinguished. As is apparent from Figure 2, the spacing between the rays of the future finlets is greater than between the rays of the soft dorsal and anal fins. Further demarcating the finlets is the dusky pigment of their membranes. Following finlet formation this fish would presumably have had fin formulae of D XXVII, 14 + 10 and A 12 + 10.

Other characters of this specimen are 23 pectoral rays, I, 5 pelvic rays, 7 branchiostegal rays, and 17 principal caudal rays. All caudal rays, except the 5 mesial ones, have their bases covering the hypurals, tending to conceal the latter. The gill filaments are J-shaped but as yet show no tendency to fuse into the adult gill reticulum. Tooth size and spacing are irregular, in contrast to the homodont adult dentition, with about 28 teeth on each dentary and 25 on each premaxillary. The anterior teeth in both jaws are curved and fanglike. The anterior margin of the preopercle bears a short spine at the angle and another on the lower limb. The posterior margin has two short spines on the upper limb, a long spine at the angle, and five irregular spines on the lower limb. There are two tiny spines on the posterior tip of the pterotic, but these are too small to appear in the drawing. The body is dusted with tiny melanophores, giving a uniform tan color, except on the dorsal part of the snout, which is dark brown.

An unusual feature of this specimen is a conical cartilaginous projection surmounting the mandibular symphysis. This projection has been noted in the adult, but not commented upon (Conrad, 1938:10). A similar structure has phylogenetic significance in relating the Gempylidae and Trichiuridae (Tucker, 1956:123), as well as taxonomic importance within the Gempylidae (Grey, 1953:138). Because its presence in *Acanthocybium* was thought to indicate hitherto unsuspected relationships between the Scombridae and the Gempylidae-Trichiuridae, a search was made for the structure in other scombroids. There is no indication of it in the young of any of the tunas (*Auxis, Euthynnus, Germo, Katsuwonus, Neothunnus, Parathunnus,* and *Thunnus*) according to W. M. Matsumoto (personal communication), but a prominent mandibular protuberance was found in juvenile *Scomberomorus maculatus,* 11.5–19.2 mm in standard length. *Scomberomorus* is regarded as phylogenetically basal to *Acanthocybium* (Fraser-Brunner, 1950:135), and the presence of this jaw projection confirms a close relationship. That there is a tie between these genera and the Gempylidae-Trichiuridae is further indicated by their mutual low-crested crania, elongate compressed bodies, and reduced squamation. In all scombroids examined, including a 565-mm

Gempylus serpens, the jaw protuberance is flexible (and sometimes decurved in *Nesiarchus nasutus*), precluding its use as a spear, and instead suggesting a hydrodynamic function (cf Wisner, 1958: 68).

Nealotus tripes Johnson

Station 2	1 specimen:	176 mm
Station 32	10 specimens:	16.4–41.5 mm
Station 49	8 specimens:	19.6–25.8 mm
Station 51	59 specimens:	10.0–20.2 mm
Station 53	3 specimens:	10.0–22.0 mm
Station 56	4 specimens:	9.0–24.0 mm
Station 58	6 specimens:	21.2–25.0 mm
Station 60	2 specimens:	21.4–28.0 mm
Station 70	1 specimen:	37.0 mm

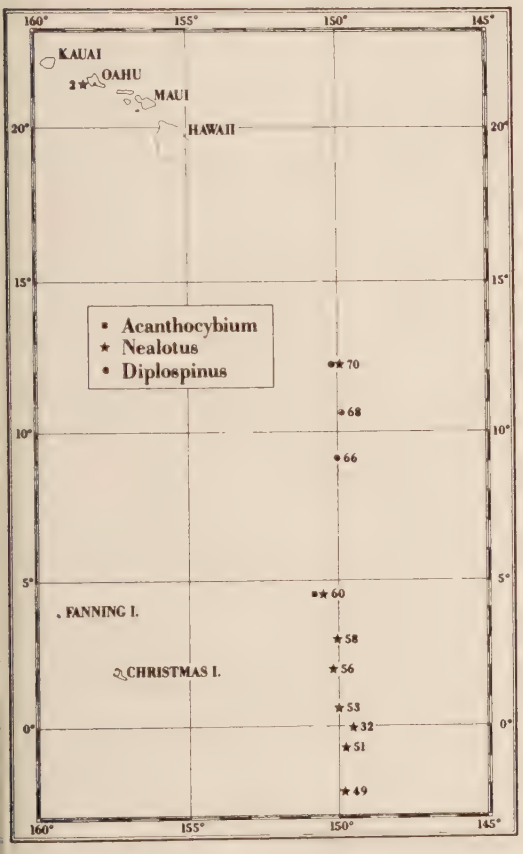

FIG. 1. Trawling stations on "Hugh M. Smith" cruise 47, showing places of capture of *Acanthocybium, Nealotus,* and *Diplospinus.*

When first examined, the smaller specimens listed above were thought to be *Nesiarchus nasutus* Johnson, to which they bear a strong superficial resemblance (cf Voss, 1954). Subsequent staining revealed their salient taxonomic feature, a reduction in the number of pelvic rays, showing that they belonged in a different branch of the Gempylidae, the *Rexea-Promethichthys-Nealotus* group. According to Grey (1953:139), these genera are characterized by a reduction of the pelvic fins to a pair of spines, or by the total absence of these fins. Only the largest of the above specimens, a fish 176 mm in length, has the pelvics reduced to mere spines and thus is referable to *Nealotus tripes.* The remainder range from 9.0–41.5 mm, and have pelvic formulae of I,2 or occasionally I,1 (Table 2). In this length range, as is shown in the following paragraphs, the pelvic rays gradually become overgrown by abdominal tissues, within which they are clearly visible after alizarin staining. At larger sizes the rays presumably are too deep to be seen without dissection or staining. Norman (1930:351) failed to find them in *N. tripes* specimens 53 and 88 mm long. Dissection of the pelvic region of my 176-mm fish revealed fragments of raylike material in the musculature ventral to the pelvic bones. These fragments were fused to the pelvis anteriorly, and appeared to serve as anchoring struts.

In young *Nealotus* individuals there are two prominent spines preceding the anal fin, whereas adults are generally regarded as having only one. My 176-mm specimen conforms to the adult concept externally, but when dissected its perianal region contained a small, flat spine, triangular in outline, embedded behind the first. Matsubara and Iwai (1952:207) also noted a second anal spine, but in their 199-mm fish it is shown as being externally visible.

With an ontogenetic loss of pelvic rays and anal spines, the genus *Nealotus* (and perhaps others) becomes more difficult to define. Characteristic counts are given in Table 2, along with data for *Nesiarchus nasutus,* a species of similar appearance.

Figure 3 depicts the smallest *Nealotus* examined, a fish 9.0 mm in standard length. At this size the vertical fin rays have not all differentiated, the dorsal being XX-I,18 and the anal

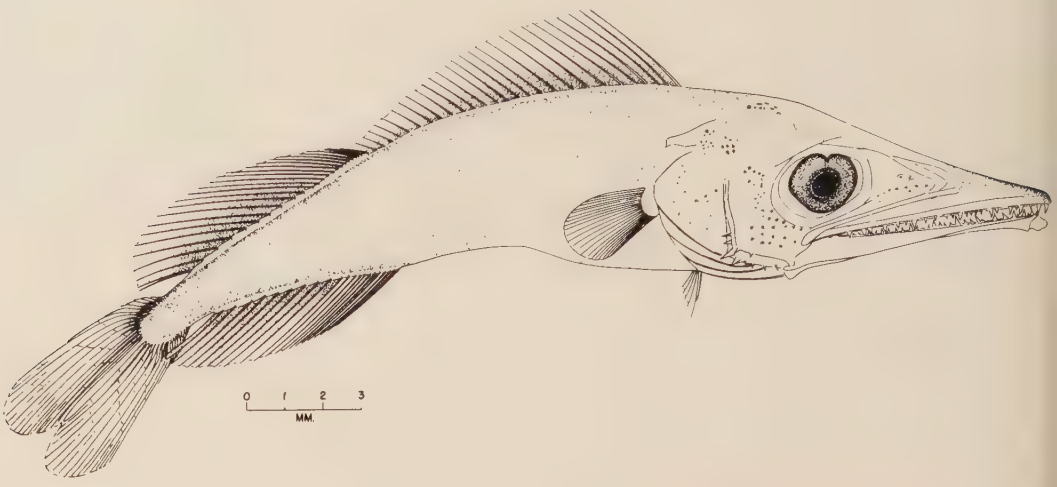

FIG. 2. *Acanthocybium solandri* 23.7 mm in standard length.

II-I,15, with both fins showing rudimentary raylike structures in the membranes posterior to the fins. The principal caudal rays number 9 + 8, the pectorals 13, and the pelvics I,2. Each pelvic spine is long, triradiate in cross-section, and spinigerous on all three edges. The inner pelvic ray is not only much shorter than the outer, but is also membranously bound to the belly anteriorly, whereas the outer ray is free. Like the pelvics, the dorsal spines are triradiate and spinigerous, with the degree of spinulation decreasing posteriorly. The first two dorsal spines bear spinules on all three edges while the rest bear them only laterally; in addition, the number of spinules per spine decreases toward the rear of the fin. The anal spines are like two spiny-edged, short-handled spoons, attached by the bowls with the convex side forward, and the second nesting into the first.

The preopercle bears two strong denticulate spines at its angle and two short smooth spines on its lower limb. The pterotic has two slender spines almost perpendicular to the body surface. A row of 10 denticulations above the eye completes the head armament.

The mandible is prognathous and its tip is surmounted by a small cartilaginous pad. The mandibular symphysis is edentulous, but there are two retrorse fangs on either side of it. About seven short upright teeth are borne on the dentary. There is a large fang on each side of the premaxillary symphysis and a larger one posterior and mesial to the first. About 13 other teeth, some little more than denticulations, occur on the premaxillary. The palatines lack teeth, while the vomer bears a single prominent tooth at each posterior tip.

Pigmentation consists of a brown streak from the top of the head to the rear dorsal base, plus diffuse brown color around the dorso-anterior orbit and along the premaxillary. There is some inconsistency between specimens, probably reflecting differences in chromatophore contraction at death rather than the presence of more than one species.

The 15.6-mm fish shown in Figure 4 differs from the 9-mm one principally in having achieved the adult fin complement (D XX-I, 19 + 2; A II-I, 16 + 2). The two dorsal and anal finlets are connected to each other and to the preceding fins, being detectable only by a variation in spacing. The pelvic spines are as before, but the rays are now adnate to the belly for about half their length. The anal spines have developed a keel on their previously smooth anterior surfaces.

The head armament consists of the two spines at the angle of the preopercle (these now having lost their denticulations), two short spines on the lower limb of the preopercle, a single perpendicular spine on the pterotic, and two pos-

erior spinelike extensions of the strengthening ibs of the opercle. The supraorbital denticula- ions have been reduced to one or two.

Both the mandible and the upper jaw now bear small cartilaginous symphysial pads, and the dentition is much advanced. Besides the anterior pair of fangs, each dentary has 11 slightly retrorse teeth, and 12 similar teeth are found along the edge of each premaxillary. Anteriorly the premaxillary has 3 or 4 large curved fangs, the posterior ones longest, and all larger than the fangs on the dentary. The vomer has a posterior tooth on each side, and there are about 4 slender teeth located on or near each palatine. Those which are merely near the palatines lack ossified bases. There are as yet no gill-rakers on the first arch.

Pigmentation is again inconsistent between specimens, except for a pronounced dark spot between the first two dorsal spines. Well-marked individuals are colored as is the 9-mm fish; others lack the dark pigmentation of the head and dorsal fin base.

At 31.0 mm (Fig. 5) many of the larval features have been replaced by juvenile characters. The dorsal finlets are still interconnected

TABLE 2

COUNTS MADE ON *Nealotus tripes* AND *Nesiarchus nasutus**

PART	NO.	*Nealotus tripes* (No. specs.)	*Nesiarchus nasutus* (No. specs.)
First dorsal spines	19		21
	20	62	2
	21	1	
Second dorsal spines	1	63	23
rays	17	26	
	18	35	4
	19	2	8
	20		10
	21		1
Dorsal finlets	2	63	23
Anal spines	2–1	25	23
rays	15	2	
	16	14	4
	17	9	17
	18		2
Anal finlets	2	25	23
Pectoral rays	12		2
	13	24	21
	14	1	
Pelvic spines	1	64	21
rays	0	1	
	1	5	
	2	58	
	4		3
	5		18

* Standard length range: *Nealotus*, 10.0–176 mm; *Nesiarchus*, 11.7–105 mm. Finlets listed as such even if attached to fins by persistent membranes.

FIG. 3. *Nealotus tripes* 9.0 mm in standard length.

but are free from the last dorsal ray. The same is true of the anal finlets, except that there is a persistent basal membrane between the last anal ray and the first finlet. The dorsal spines have lost the spinules from their anterior edges, and the lateral spinules are less prominent on all fin spines, the space between the spinules having become filled with bony material. The pelvic rays are both buried in epidermal tissues, with the short mesial ray lying deeper than the long lateral one.

The upper spine at the preopercular angle is prominent, but the lower is broad and scarcely noticeable. The lower preopercular limb is smooth, and the opercular spines are reduced in size. The cartilaginous protuberance at the tip of each jaw is conical and well developed. The dentary has 2 anterior fangs and 13 variably smaller teeth; the premaxillary bears 3 anterior fangs and about 16 smaller teeth. The vomer has 2 teeth on each posterior tip, and there are about 6 teeth on or near each palatine. As before, some of the latter are attached to unossified material on the roof of the mouth. There are 3 + 1 + 8 gill-rakers on the first arch, the one at the angle being much larger than the others.

A new feature is the lateral line, a few scales of which are visible on the 31-mm fish. These lie in the skin and are better developed and more numerous anteriorly. In a 35-mm specimen (not shown) the lateral line is nearly completely developed. It is a tubelike structure containing 78 scales and extending from the head to the caudal peduncle. Scale spacing is occasionally irregular, suggesting incomplete development or loss through damage.

Pigmentation consists of rows of tiny, close-set, dark dots, giving an over-all tan color. This is intensified on top of the head, at the jaw tips, along the dorsal base, on the sides of the caudal peduncle, and around the anal spines. The fins lack pigment except for a distal dark spot between the first three dorsal spines.

A 41.5-mm fish (Fig. 6) is essentially a juvenile. Persistent larval features include the slightly denticulate fin spines, the absence of scales except in the lateral line, and basal membranes between the finlets. The pelvic rays are embedded, the two preopercular and two opercular spines are reduced in size, and the symphysial jaw pads are less prominent (and now decurved in the case of the upper jaw). The teeth have increased slightly in number, there now being 3 anterior fangs and 19 lateral teeth on the premaxillary, 2 fangs and 16 lateral teeth on the dentary, 8 or 9 teeth on each palatine (all firmly ankylosed to the palatine and none free on the roof of the mouth), and 1 or 2 elongate teeth posteriorly on each side of the vomer. There are 94 scales in the lateral line but none elsewhere. There are 3 + 1 + 8 slender gill-rakers on the first arch. Pigmentation is as in the 31-mm fish, except that there are now indications of distal dark spots between the first four dorsal spines.

It is unnecessary to figure my 176-mm fish, r it has essentially the same features as the 99-mm specimen shown by Matsubara and vai (1952:208). As noted earlier, it differs in ving the second anal spine embedded. Other ita from my specimen are as follows. The wer jaw has a rudimentary symphysial pad, or 2 anterior fangs on each side, and a row of lateral teeth set closely together like the teeth a saw. On the premaxillary are 3 large ante- or fangs and a row of 21 closely-spaced lateral eth. The symphysial pad of the premaxillary blunt, decurved, and scarcely noticeable. The of of the mouth is overgrown by membranes hich, when removed, reveal an edentulous omer. There are 8 short, blunt denticles on ch palatine. The gill-rakers consist of numer- us spinules so variable in size, position, and acing that they cannot be enumerated (cf latsubara and Iwai, 1952:209). The specimen partially skinned and the lateral line scales nnot be counted.

iplospinus multistriatus Maul

Station 66	2 specimens: 103 and 166 mm
Station 68	10 specimens: 10.0–17.4 mm
Station 70	1 specimen: 156 mm

The genus *Diplospinus* is known from Ma- eira, the West Indies, and the Philippine–East ndian region (Tucker, 1956:79). The above ecimens are the first from the central Pacific cean. Postlarvae are hitherto unknown, al- hough they and earlier stages have been found r other trichiurids (Delsman, 1927; Padoa, 1956:508–513; Regan, 1916:144–145). The following descriptions and figures illustrate development in which a short, high-bodied postlarva becomes an increasingly attenuate juvenile.

As pointed out by Tucker (1956:81), there is a possibility that *Diplospinus multistriatus* Maul is a synonym of *Lepidopus gracilis* Brauer. The latter was described from a specimen 69 mm in length (Brauer, 1906:291), which differs from *multistriatus* chiefly in characters which change with growth. Although it was impossible to examine the type of *gracilis*, a brief study was made of a feature thought to distinguish it from *multistriatus*, the ratio of standard length to head length. This ratio is plotted against standard length in Figure 7. The data represent the present specimens, the type series of *multistriatus* as described by Maul (1948:45), a recently collected 65-mm *multistriatus* with a SL/HL ratio of 5.5 (Maul, in litt.), and the type of *gracilis*. The curve was derived from the regression of head length on standard length, $\hat{Y} = 3.397 + 0.1350X$, calculated from the above *multistriatus*.

From Figure 7 it would seem that *multistriatus* and *gracilis* are separate species. This is confirmed by the fiducial limits of the head length of *multistriatus* 69 mm in standard length (the length of Brauer's *gracilis*). At this size one can expect a head-length range of 12.3–13.1 mm, using $P_{.01}$ values of t and the formula

$$S\hat{Y} = \sqrt{\frac{1}{n} + \frac{x^2}{Sx^2}}$$

(Snedecor, 1946:120). The 14.25-mm head

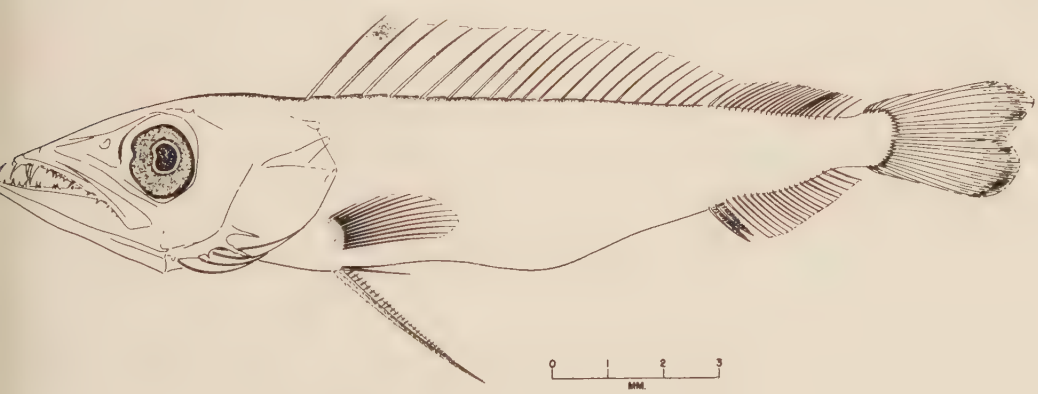

FIG. 4. *Nealotus tripes* 15.6 mm in standard length.

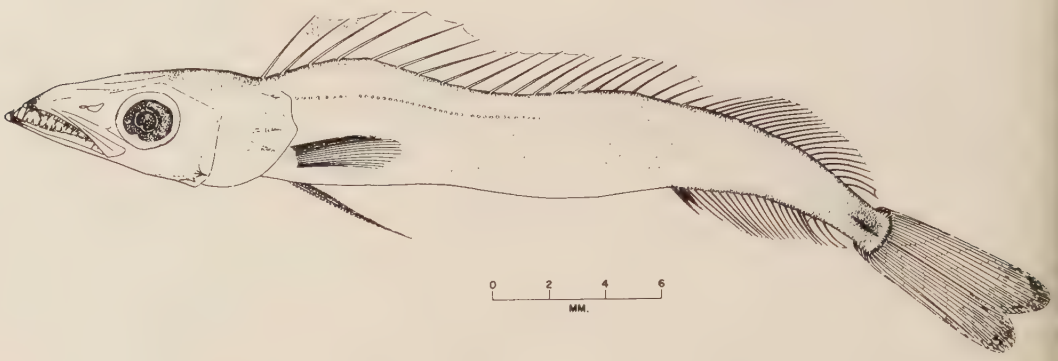

FIG. 5. *Nealotus tripes* 31.0 mm in standard length.

length of *gracilis* lies significantly distant from this range, and the two forms are therefore considered distinct species.

Because not all postlarvae in the 10.0–17.4 mm length range have acquired the adult fin ray complement, it is necessary to list meristic and length data conjointly in Table 3. The number of dorsal and anal fin rays increases irregularly with size. The pectoral, pelvic, and caudal fins and the branchiostegal rays show little or no meristic variation. Except for one specimen with 13 rays on one side and 12 on the other, the pectoral was constant at 12 rays. There were 7 branchiostegal rays and 9 + 8 principal caudal rays, the latter being difficult to count because of damage or nonattainment of definitive shape. In all 13 specimens the pelvic fins are represented by a pair of stout denticulated spines, in agreement with Maul's findings (1948:42) but not with Tucker's (1956: 79–81). The latter, working with a "completely skinned" paratype, observed "Ventral fin I–I; a narrow scale-like spine and an external split ray twice as long." Palmer and Marshall (*in litt.*) have re-examined this paratype but failed to find the external split ray, observing only the scale-like spine and the pelvic bones. I suggest that Tucker's "ray" was in reality the splintlike pelvis, perhaps loosened in its muscular bed by the force which skinned the fish. In my specimens the attenuate pelvis bears a marked resemblance to a soft ray and is, coincidentally, just twice as long as the pelvic spine.

The most distinctive feature of the 10.0-mm postlarval *Diplospinus* is its relatively great depth at mid-length. As shown in Figure 8, this is caused by a ventral distension of the belly by the elongate pelvic bones, a condition reminiscent of the Balistidae and Monacanthidae, except that in *Diplospinus* the pelvis extends posteriorly. The great depth of *Diplospinus* is quite different from the narrow belly of *Lepidopus* at

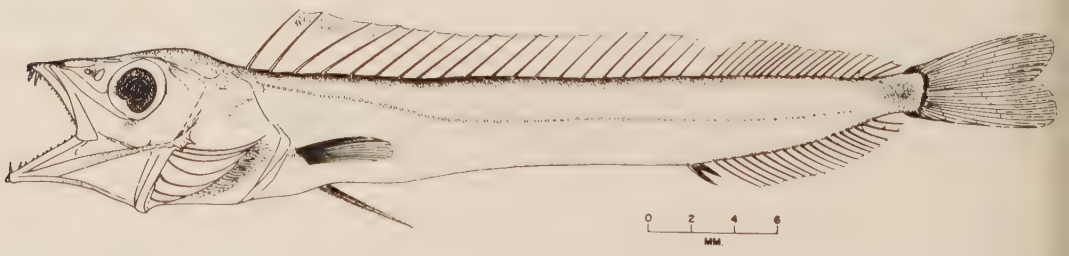

FIG. 6. *Nealotus tripes* 41.5 mm in standard length. The eyes are lacking in this specimen, but have been drawn as they appear in another of about the same size.

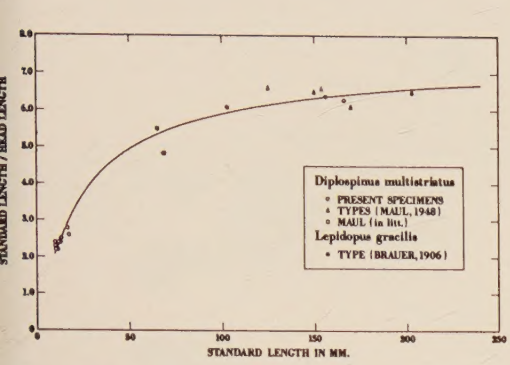

FIG. 7. Standard length/head-length ratio of *Diplospinus multistriatus* and *Lepidopus gracilis*.

this size (Regan, 1916: fig. 7). The abdominal walls of *Diplospinus* are braced laterally by the very long, slender postcleithra.

Attached to each pelvic bone is a hypertrophied pelvic spine, V-shaped or nearly triradiate (through attenuation of the V's apex) in cross-section, with about 20 spinules along each of its three edges. The two detached anal spines and the anterior four or five dorsal spines are similar to the pelvics in shape and armament, while the others are smooth and less obviously triradiate. The low number of soft dorsal rays (Table 3) is probably attributable to damage rather than youth, for a 10.4-mm specimen has 10 more rays in this fin.

The head is armed with a long slightly serrated spine at the preopercular angle, a shorter spine just above it, and two other short spines below, the last three spines being smooth. The three strengthening ribs of the upper opercle project from the opercular edge as slender spines. Dorsal to these projections are two spines at right angles to the body surface: a stout serrated spine on what is probably the pterotic, and a slender smooth one on the post-temporal. Two short spines occur above each eye.

A pair of stout anterolaterally directed tusks lies at each side of the symphysis of the prognathous mandible, these being ventral to the jaw edge, horizontal in position, and unopposed by other teeth. Behind them are three or four retrorse denticles in the anterior half of each dentary, with no teeth posteriorly. The premaxillary has an enlarged tooth at either side of the symphysis, one or two retrorse denticles lateral to this, and six or seven tiny denticles scattered along the rest of its length. The vomer and palatines are ossified but edentulous. There is no trace of a cartilaginous jaw protuberance.

Pigment is restricted to a brown spot distally in the membrane between the first three dorsal spines.

At 13.2 mm (Fig. 9) the postlarva has become more elongate and less high-bodied. There is a variable increase in the number of dorsal and anal rays, and the spinigerous condition has spread posteriorly to include three-fourths of the dorsal spines. The caudal fin is beginning to fork. The preopercular spines are as before, while the post-temporal and pterotic spines are equal in size and both are smooth. The supraorbital spines are short and inconspicuous. A peculiarity of this specimen is its possession of only two opercular-strengthening ribs, each with a spinelike projection. The normal number of ribs, and spines, is three.

Just posterior to its nearly horizontal tusks each dentary bears an upright, unopposed tooth, and behind this is a row of eight emergent teeth extending to the rictus. The premaxillary has a pair of curved fangs on each side of the symphysis, followed by about six teeth of varying size extending to the rictus. The vomer has two prominent teeth on each posterior tip, while the palatines lack teeth. A cartilaginous pad has not yet appeared at either jaw tip. The nasal capsule is visible as a yellowish sub-epidermal sac which lacks external ducts.

TABLE 3

COUNTS MADE ON *Diplospinus multistriatus*

STANDARD LENGTH (mm)	DORSAL FIN	ANAL FIN
10.0	XXX, I, 16*	II–I, 19
10.4	XXX, I, 26	II–I, 20
11.1	XXXI, I, 25	II–I, 19
11.2	XXXII, I, 29	II–I, 22
12.0	XXX, I, 27	II–I, 23
12.1	XXXII, I, 27	II–I, 20
12.6	XXX, I, 30	II–I, 29
13.2	XXXI, I, 30	II–I, 23
16.5	XXXI, I, 33	II–I, 27
17.4	XXXI, I, 35	II–I, 28
103	XXX, I, 37	II–I, 31
156	XXXII, I, 35	II–I, 28
166	XXXII–I, 38	II–I, 30

* Damaged (?).

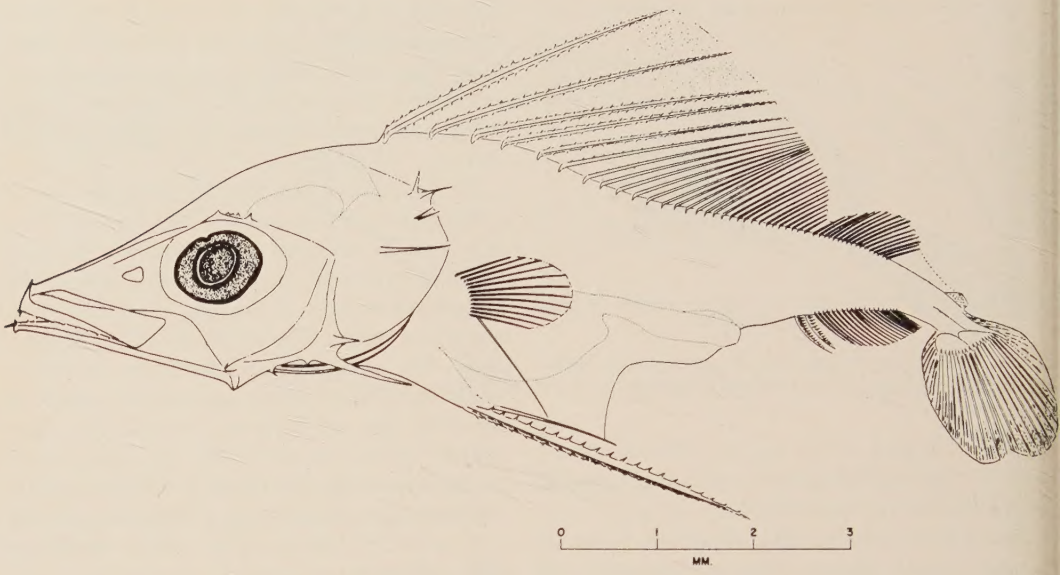

FIG. 8. *Diplospinus multistriatus* 10.0 mm in standard length.

Pigment consists of the distal brown spot in the spinous dorsal, large melanophores on top of the head and occiput, and diffuse brown color anterior to the eye, posteriorly on the maxillary, in front of the pelvic bases, and on the branchiostegal membranes.

Definite indications of the forthcoming ribbon shape are seen in the 17.4-mm postlarva (Fig. 10). There is little trace of the earlier abdominal distension and the head is relatively short. The adult fin ray complement has been attained, although the fins are immature in that their spines still bear spinules. The pelvics are still excessively large and the caudal is well forked.

On the head, the preopercular spines are as before except that those on the lower limb are shorter and stouter. The opercular ribs and

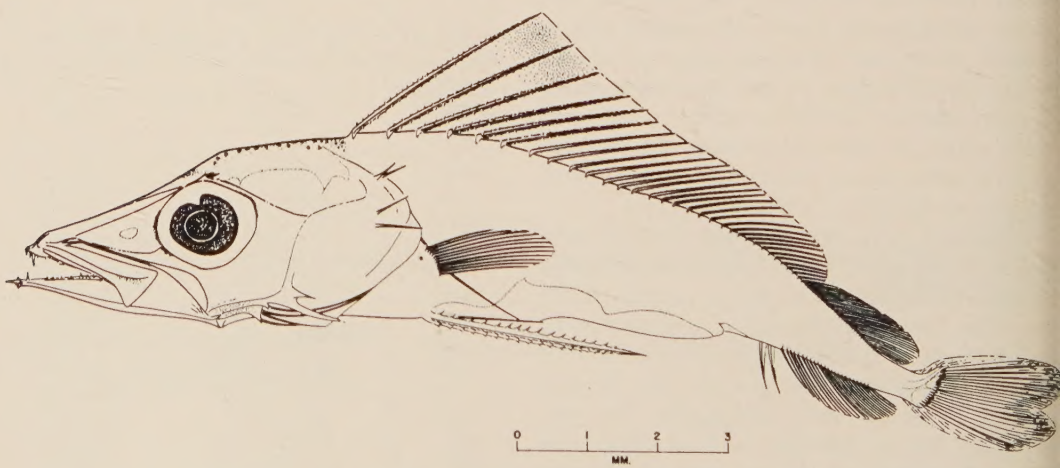

FIG. 9. *Diplospinus multistriatus* 13.2 mm in standard length.

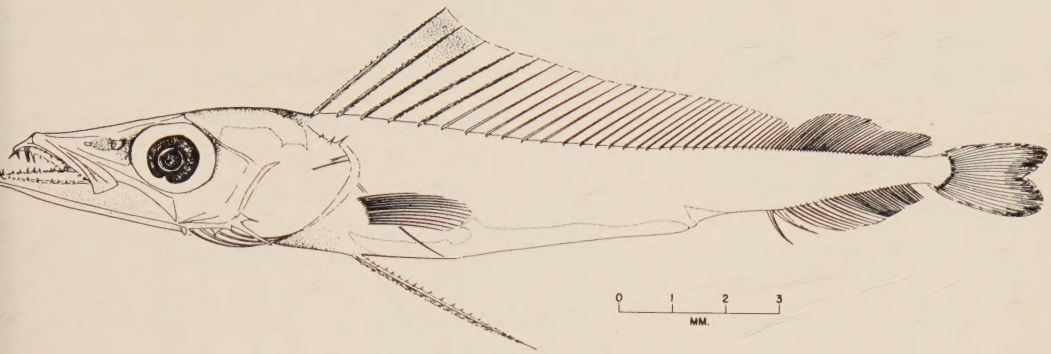

FIG. 10. *Diplospinus multistriatus* 17.4 mm in standard length.

pines and the post-temporal and pterotic spines re likewise little changed. A single low spine, ctually little more than a crest, occurs above ach eye. The upper of the two tusks on the lentary is much the larger, and the upright tooth osterior to the tusks equals it in size. About 5 curved teeth, some occurring as pairs, occupy he length of the dentary. Anteriorly the premaxillary has 3 or 4 greatly enlarged fangs, the nterior 1 or 2 about half the size of the others. Behind the fangs is a row of about 10 short eeth similar to those of the dentary. The vomer till has 2 teeth near each posterior tip, and hese are attached on the inner surface of the one rather than to its crown. Each palatine ears 6–8 short denticles. There are 3 + 1 + 11 ong, slender gill-rakers on the first arch. The asal capsule has 2 openings, an oval anterior ostril and an irregular posterior one. The nostrils must form suddenly, for they are not present in a 16.5-mm specimen. Small patches of cartilage surmount the tips of both jaws, where they appear to do nothing more than smooth over irregularities in the bones.

Large melanophores occur on top of the head, but give way to smaller ones which extend in a narrow line from the occiput along the entire base of the spinous dorsal. Dark pigment overlies the nasal capsule and occurs as a ring around the orbit. The maxillary, posterior dentary, and pre-pelvic and branchiostegal regions are also dusky, and there is a dark spot in the spinous dorsal fin membranes. (These membranes are damaged in the 17.4-mm fish and the spot is drawn as it appears in a 16.5-mm specimen.)

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